# GEOLOGY OF THE OROVILLE QUADRANGLE CALIFORNIA

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COVER PHOTO: CHEROKEE MINE, BY MARY R. HILL, 1962

# Geology of the Oroville Quadrangle, California


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## ABSTRACT

Oroville quadrangle is in Butte County, in central northern California, and lies athwart the border between the Sierra Nevada and the Sacramento Valley.

The stratified rocks of the area may be grouped into the steeply dipping "Bedrock series" and the younger, nearly flat-lying "Superjacent series". The two sequences are separated by a profound angular unconformity. The metamorphism, steep dips, tight folds, and thrust faults of the "Bedrock series" stand in marked contrast to the low dips and undeformed condition of the "Superjacent series". Some of the bedrock was probably folded at the end of the Paleozoic, but the dominant structural features of the bedrock terrane were formed or greatly accentuated during the Nevadan revolution in the Late Jurassic. Mild uplift, without deformation, has occurred sporadically until rather recent times.

Outcrops of the "Bedrock series" are restricted to the eastern quarter of the area. The oldest (?) formation is unnamed and consists of schistose to massive, low-grade metavolcanic rocks of basic to intermediate composition which are probably of late Paleozoic age. This unit is overlain by the Upper Paleozoic Calaveras Formation, which includes black slate, low-grade metavolcanic rocks, sheared graywacke and conglomerate, together with bedded chert and minor limestone. Stratigraphically above the Calaveras Formation are the slightly metamorphosed volcanics and volcanic sediments of the Oregon City Formation, probably Middle Jurassic in age. The Monte de Oro Formation of Middle Jurassic age overlies the Oregon City Formation. It includes thin-bedded graywacke, sheared siltstone, conglomerate, volcanic sandstone, and slate. Intrusive masses of serpentine, metagabbro, basalt porphyry, monzonite, and various other rocks are largely restricted in their occurrence to the Paleozoic terrane.*

The oldest rocks of the "Superjacent series" are in the Upper Cretaceous Chico Formation, consisting of fossiliferous marine sandstone with conglomerate and shale. Equivalent to, or younger than, the Cretaceous sediments is the "greenstone gravel", which fills the deepest part of an exhumed stream channel. Above the Chico Formation are marine shale and sandstone of the "Dry Creek" Formation (middle Eocene). Middle Eocene deltaic sediments of the Ione Formation and contemporaneous stream channel and flood plain deposits of the "auriferous gravels" overlie the "Dry Creek" Formation and "greenstone gravel", respectively. Tertiary volcanism is represented by the Mehrten (?) andesitic rocks and by the "older basalt" (upper Miocene to lower Pliocene?). The New Era Formation, probably of Pliocene age, includes conglomerate, sandstone, and siltstone which fill ancient stream channels. The Tuscan Formation (upper Pliocene) consists of basaltic and andesitic tuff-breccia, tuff, volcanic sandstone, conglomerate, siltstone, and claystone, and includes the Nomlaki Tuff Member at its base. The coarse fluviatile sediments of the Red Bluff Formation were deposited during the Pleistocene by the ancestral Feather River.*


* *Recent information on the ages of these formations suggests that the Oregon City is Upper Jurassic; the Monte de Oro, Upper Jurassic; the Mehrten (?), lower Miocene; the "older basalt", lower Miocene; and the New Era, Pliocene (?). Dr. Creely has provided footnotes regarding these new age assignments on the pages on which the units are discussed. . . . Edit.*

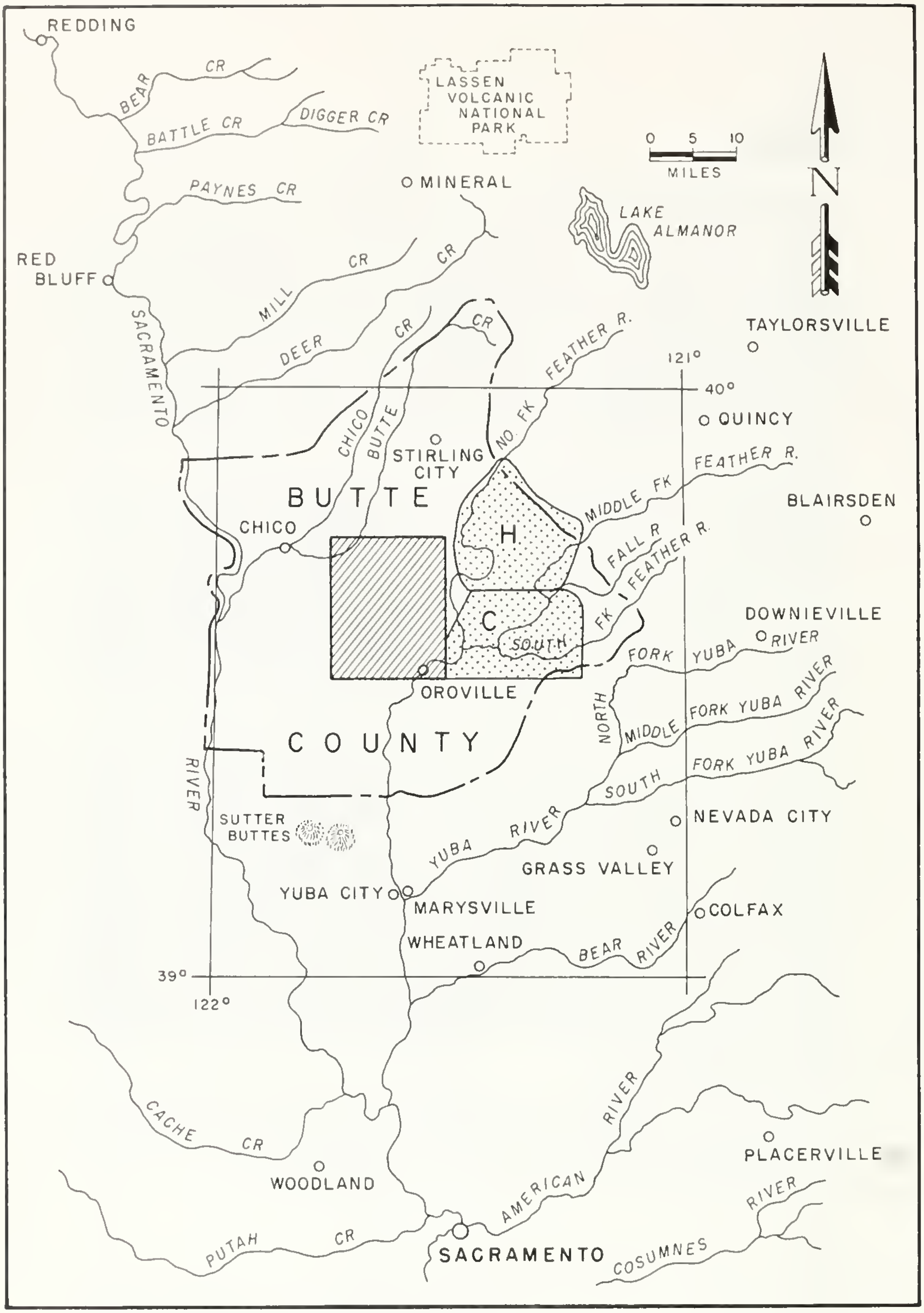



Figure 1. Index map of part of northern California, showing location of Oroville quadrangle and adjoining mapped areas. H, Hietanen, 1951; C, Compton, 1955.

# GEOLOGY OF THE OROVILLE QUADRANGLE, CALIFORNIA

By ROBERT SCOTT CREELY

## INTRODUCTION

The Oroville quadrangle encloses approximately 240 square miles near the center of Butte County, in central northern California. The area is situated about midway between Sacramento on the south and Redding on the north. Oroville (pop. 6,100), the county seat, lies near the southeast corner of the quadrangle on the southeast bank of the Feather River. The only other sizeable community is Paradise, at the north border of the area.

The United States Geological Survey topographic maps used as base maps, all with a scale of 1:24,000, were the Oroville (edition of 1949), Cherokee (edition of 1949), Hamlin Canyon (edition of 1951) and Shippee (edition of 1950) quadrangles. Aerial photographs of part of the area were also used. The results were compiled on the U.S.G.S. Oroville topographic map (edition of 1944, scale, 1:62,500). Approximately 9 months were spent in the field during the summers of 1950, 1951, and 1953, and the spring of 1954.

## ACKNOWLEDGMENTS

To my wife, Dorothy, I express sincere gratitude for her constant encouragement and help during the final two years of the study. The writer is especially indebted to the late Professor N. L. Taliaferro for suggesting the problem, for accompanying the writer in the field on several occasions, and for giving freely of his knowledge of geology in general and of Sierran geology in particular. Professor Garniss H. Curtis also visited the area and participated in many stimulating discussions regarding the various aspects of the problem. Professors C. M. Gilbert, Francis J. Turner, and Howel Williams on many occasions aided the writer in problems relating to petrology. To Professors J. Wyatt Durham, Ralph W. Chaney, and R. L. Langenheim of the University of California, and to Dr. L. G. Hertlein of the California Academy of Sciences, go the writer's sincere appreciation for identifying fossils from the area. Miss Helen E. Bailey, formerly librarian of the Department of Geological Sciences, University of California, helped prepare the bibliography and her kindness is gratefully acknowledged. Members of the California Division of Mines, particularly Mort D. Turner and Oliver E. Bowen, aided the writer in many ways. Drs. Olaf P. Jenkins and Gordon B. Oakeshott accompanied the writer in the field and made several helpful comments. Mr. T. C. Slater of the Calaveras Cement Company kindly provided the aerial photographs of the Cherokee hydraulic mine included herein. Others who helped further the project by furnishing geologic information are Professor Robert R. Compton, Stanford University, Messrs. W. W. Paulsen and R. Rongey, U. S. Bureau of Reclamation, Mr. J. R. Jackson, Humble Oil and Refining Company, and Mr. E. K. Craig of Healdsburg.

The writer is grateful to the many landowners and mining men in the area without whose cooperation the study would not have been possible. Particularly hospitable were the late Mr. and Mrs. S. J. De Long of Cherokee, Mr. and Mrs. G. L. Dimmick of Yankee Hill, Mr. H. H. Lavarans of Cherokee, Mr. Bert Johnston of Paradise, Mr. J. O. Gaumer, part owner of the Jack and Jim mine and Mr. J. H. Sharpe, President and General Manager of the Morris Ravine Mining Company. Mr. Bruce Armstrong of Paradise guided the writer to several fossil localities and Mr. Ron Johnston of Paradise assisted in the field for a brief period. The Board of Research, University of California, Berkeley, furnished material aid to defray the major part of expenses incurred in the field and laboratory.

## GEOGRAPHY

*Accessibility.* Most parts of the Oroville quadrangle are easily accessible from an excellent system of roads. The main transcontinental line of the Western Pacific Railroad passes through Oroville and the eastern portion of the quadrangle. Tracks of the Sacramento Northern Railway transect the southwest quarter of the area, and a short branch line runs from Oroville Junction as far east as Thermalito.

*Climate and vegetation.* The Oroville quadrangle is characterized by rather hot, dry summers and wet, mild winters. Rain falls intermittently, beginning in September and ending in March, and some snow falls at the higher elevations. Occasional thunderstorms occur during the spring and summer. Fog often collects in the lower parts of the area during the winter.

The local distribution of the various types of vegetation in the area is controlled to some extent by availability of water and the type of soil present, but the

Figure 2. View northwest from mouth of Flag Canyon, showing dissected late Pliocene constructional plain (distance), which dominates the topography of the northwest quarter of Oroville quadrangle.

Figure 3. Narrow canyon of Concow Creek near junction with West Branch. View downstream (southwest).

Figure 4. View northwest from Rocky Peak, showing flat or gently rounded tops of ridges and steep-sided canyons typical of the northeast part of the quadrangle. Glover Ridge at left; canyon of West Branch near center of photograph. In distance is dissected southwest-sloping constructional plain of the Tuscan Formation.

Figure 5. View northeast from near Lime Saddle toward canyon of West Branch. Cape Horn left of center. Nelson Bar bridge at lower right. Even sky-line represents destructional surface cut on bedrock in pre-Tuscan time.

Figure 6. West branch of Feather River near Glover Ridge, showing bench cut in bedrock. View upstream (northwest).

Figure 7. Feather River near Morris Ravine, showing broad bench cut in bedrock. South Table Mountain in distance. Large wall on bench was once used to divert river in order that the main channel might be mined for placer gold. View northwest.

overall distribution is unmistakably influenced by elevation. The flat or low, rolling plain of the Sacramento Valley is grassland with occasional oak trees. Oak increases in density at the edge of the foothills, and the slopes just above the level of the valley are characterized by abundant oaks and Digger pines. Oregon ash and various species of willow, cottonwood, and sycamore grow abundantly on the banks of the larger streams. In parts of the lower foothills, patches of dense chaparral, consisting largely of manzanita, buck brush, and scrub oak are interspersed with open, grassy clearings. Moderately thick stands of ponderosa pine and Douglas fir characterize the tops of ridges and hills in the northeastern part of the quadrangle.

*Topography and drainage.* The Oroville quadrangle lies on the southwest margin of the foothills bordering the northern Sierra Nevada. Approximately one-third lies in the Sacramento Valley, which is characterized by a broad, nearly flat plain with alluviated narrow tributary valleys. Elevations in the valley proper range from 104 feet at the southwest corner of the quadrangle to approximately 250 feet at the margin of the foothills. Except in that part of the area adjacent to Oroville Table Mountain, the foothills rise rather gradually toward the northeast, culminating at a maximum elevation of 2800 feet at the northeast corner of the quadrangle. The physiographic stage of development ranges from late youth in the higher parts of the area to old age in that part of the area lying within the Sacramento Valley.

Oroville Table Mountain, a conspicuous nearly flat-topped mesa resulting from erosion of an ancient lava flow, rises rather abruptly above the plain of the Sacramento Valley. Much of the northern one-third of the area is dominated by a gently southwest-sloping late Pliocene constructional plain which has been dissected into a series of long, finger-like, flat-topped ridges separated by steep-sided, more or less straight canyons. Most spectacular is the gorge cut by Butte Creek, which flows southwestward across the northwest corner of the quadrangle. The ridges, at their lower ends, pass gradually beneath the alluvium of the Valley without interruption or, more often, are dissected into a series of low buttes (Fig. 2).

East of this spectacular front of mesas and long ridges uplands of Sierran bedrock rise above a few deep major stream canyons (Fig. 3). The uplands have been dissected into rounded or somewhat flat-topped ridges and hills (Fig. 4). Viewed from a distance, the summits of the uplands together appear to form a gently undulating, but essentially planar, surface (Fig. 5) which slopes a few degrees toward the southwest.

The largest stream in the area is the Feather River, which flows out of the foothills and into the Sacramento Valley just above Oroville, thence joining the Yuba River at Marysville. The west branch of the north fork of the Feather follows a rather devious course through the northeast quarter of the quadrangle. The two streams together drain an area underlain largely by a bedrock complex which is characterized by structural and lithologic heterogeneity. Thus the drainage pattern within their watershed is quite irregular. Contrasted to this is the regular, consequent drainage of the western part of the area where low-dipping strata predominate. Butte Creek is the major stream in the western part of the quadrangle. Rainfall in the area is seasonal, but none of the larger canyons or ravines is wholly without water during even the dryest months.

The major streams in the eastern part of the area follow relatively deep, narrow channels cut into bedrock and are fringed, on one or both banks, by a relatively broad stream-cut bench (Figs. 6, 7). This feature may indicate that the streams have been slightly rejuvenated by mild uplift in fairly recent times.

## STRATIGRAPHY

The rocks of the western foothills of the Sierra Nevada can be grouped conveniently into two separate and distinct divisions, the "Bedrock series" and the younger "Superjacent series", as they have been called by Lindgren and Turner (1894, p. 1). A cursory geological examination of the Oroville quadrangle or nearly any other portion of the lower western slope of the range reveals the profound unconformity which separates these two divisions. The "Bedrock series" is a complex of steeply dipping metamorphosed sedimentary and volcanic rocks which have been invaded, in places, by a wide variety of igneous intrusions. In marked contrast, the later "Superjacent series" is a nearly flat lying sequence of undeformed sedimentary and volcanic rocks which have been deposited upon the upturned, deeply eroded edges of the bedrock strata or upon unroofed intrusive bodies. In a general way, the "Superjacent series" may be envisioned as a gigantic wedge, with the thin edge toward the east, lying draped upon a westward-sloping bedrock surface.

### "Bedrock Series"

#### Unnamed Metavolcanic Rocks

Two separate belts of dark-colored, massive to schistose, amphibole-bearing metamorphic rocks, believed to have originated as basic to intermediate volcanic rocks, were mapped. On the basis of stratigraphic relations and degree of metamorphism, it is considered probable that they represent the oldest rocks in the area. The rocks of the two belts may be equivalent to one another, but because of dissimilarities between them, they are discussed separately.

*Eastern belt.* The largest outcrop area of these metavolcanic rocks lies along the east edge of the quadrangle, and extends north from the southeast corner for about 8 miles. When fresh, these rocks are typically dark greenish-gray or bluish-gray. They are extremely tough and dense and are usually massive, although schistose variants are common. Relict structures and textures are often present. In rocks thought to be metamorphic derivatives of tuff or volcanic sandstone, thin to thick bedding and, in a few cases, graded bedding are preserved. Often, too, an original clastic texture is well preserved and plainly visible. Fragmental types coarser grained than tuff or sandstone were not recognized. Metamorphosed flows are also present, but are less easily distinguished than are clastic types. Relict flow-banding, amygdules, an overall massive character, and lack of clastic structures or textures sometimes serve as criteria for their recognition. Feldspar, green amphibole, and chlorite may occasionally be recognized in hand-specimens of the metavolcanic rocks, but more often specific mineralogy is obscure.

Under the microscope, most of these rocks are seen to be more or less schistose. Relict porphyritic or clastic textures and amygdaloidal structure may often be distinguished. The dominant minerals are albite, actinolite, epidote, and, in some cases, chlorite. Clear, often untwinned albite makes up 60 percent or more of the rock. It may occur either in xenoblastic aggregates or as individual elongate crystals having very ragged faces. Less than 20 percent of acicular or fibrous pale green actinolite is typically present. In several cases, actinolite appears to have wholly replaced euhedral phenocrysts of augite with little disruption of the relict crystal outline. Epidote and clinozoisite in disseminated grains, amygdules, and veinlets constitute 5 to 10 percent of the rock. Chlorite is always present and in a few specimens makes up an estimated 20 percent of the rock. Other minerals present in small amounts include sphene, calcite, magnetite and pyrite. A few grains of highly strained quartz appear to represent relict sand grains.

At several localities, the metavolcanic rocks are intruded by thin dikes or sills of augite porphyry, whose emplacement preceded the metamorphism of the volcanics, since they themselves have been metamorphosed. In an example in the lower part of Oregon Gulch,* augite porphyry has been converted largely to actinolite-chlorite schist. The original augite phenocrysts have been flattened into clots now composed of dark green actinolite. At another point, a thin sill-like body of augite porphyry has been transformed into actinolite-chlorite schist containing blastophenocrysts of augite. Under the microscope, the augite ($2V = 52°$-$54°$, $Z \wedge C = 42°$) is seen to be partly uralitized and phenocrysts are slightly elongated parallel to the schistosity. Nearly colorless actinolite ($2V = 86°$, $Z \wedge C = 15°$) is abundant, while lesser amounts of chlorite, epidote, clinozoisite, and a small amount of untwinned albite complete the assemblage.

The metavolcanic rocks of this belt originated as flows and as tuff or volcanic sandstone of rather basic composition, as shown by their relict textures and structures and by their mineralogy. A similar conclusion was reached by Turner (1898, p. 1) and by Compton (1955, pp. 16-17) concerning rocks of like character in the Bidwell Bar quadrangle, immediately east of the area under discussion.

These metavolcanics have a maximum thickness within the Oroville quadrangle of about 4400 feet if none of the section has been repeated by unrecognized folding or faulting. However, the belt extends across strike to the east for several miles (Compton, 1955) so that the thickness of this unit may be much greater. The metavolcanic rocks of this belt dip steeply toward the east, and appear to overlie spatially the Oregon City Formation which lies just to the west. The Oregon City Formation consists of basic to intermediate volcanic rocks and associated sedimentary rocks which are notably less metamorphosed than the metavolcanic rocks of the eastern belt. The contact between the two units is quite sharp, and evidence which indicates that a fault separates them is presented in the section on geologic structure. Because of the marked difference in grade of metamorphism exhibited by these two units, it is assumed that the metavolcanics are older than the Oregon City rocks. The latter are thought to be of Mesozoic age, while the metavolcanics may be about the same age as the Calaveras Formation (Upper Paleozoic).

*Northern belt.* The second major belt of amphibole-bearing metavolcanic rocks trends west-northwest across the northeast corner of the quadrangle. Only a small segment of this belt is exposed, but it crops out extensively in the area immediately north of Oroville quadrangle. Smaller masses of the same type of rock occur on Cape Horn and near Deer Peak. These rocks are typically dark bluish-gray to nearly black on fresh surfaces, but weathering produces shades of green or bluish green. Both schistose and massive types occur, but the former are more often encountered. In some cases, those having well-defined schistosity exhibit small-scale folding about nearly horizontal fold axes. They are usually fine-grained, although some medium-grained rocks also occur. The chief mineral is black amphibole, which may be recognized in hand specimens of all but the finest-grained varieties. Feldspar is distinguishable in most of the coarser-grained specimens. Minerals less frequently identified include epidote, usually present in small veinlets traversing the rock, and pyrite, present in very minor amount.

Microscopic examination of this rock shows it to be essentially hornblende-albite-epidote schist. Schistosity is usually manifested by preferred orientation of the amphibole prisms, or less often by segregation of xenoblastic albite into lenticular laminae. The most abun-

* Oregon Gulch, unnamed on Plate 1, lies in the southeast quarter of the quadrangle; it heads in the area east of Cannon Reservoir and flows generally south through Oregon City and joins the Feather River east of Sycamore Hill.

Figure 8. Amphibole schist from north of Deadwood Creek as seen in thin-section. Development of chlorite along cleavage in hornblende; minor aggregates and euhedra of sphene. X 175.

dant mineral of the schist is green hornblende, which occurs as nearly idioblastic prisms and constitutes from 50 to 70 percent of the rock. Many of the hornblende crystals are warped or broken, indicating some post-crystallization deformation. Pale green chlorite has developed, presumably as a product of retrograde metamorphism, along cleavage cracks in the hornblende (Fig. 8). The second most abundant mineral in the schist is albite, which is usually untwinned and occurs in xenoblastic aggregates with minor amounts of quartz. It makes up 30 to 50 percent of the rock. Some of the albite carries poikilitic inclusions of quartz. Epidote, in ragged, xenoblastic grains is present in all thin-sections, and is common in several. Clinozoisite occurs less frequently. Cryptocrystalline aggregates of sphene, drawn out into long irregular patches, are often present.

The observed textural features and mineral assemblage indicate that these rocks are most likely the products of regional metamorphism of basic to semibasic igneous rocks. Although the original textures and structures have been largely obscured by metamorphism, the general fine-grained nature of the schist suggests that the original rocks were fine-grained themselves and probably of volcanic origin. That they may have been deposited in a partly subaqueous environment is indicated by the occurrence of two large lenses of bedded metachert within the amphibole schist in the area just north of Deadwood Creek.* The schist represents a somewhat higher grade of metamorphism than that shown by the eastern belt of partly schistose metavolcanic rocks, but the two may be contemporaneous nevertheless.

The amphibole schist of the northern belt has a maximum thickness within the area of study of about 4000 feet. It is in contact with metavolcanic and metasedimentary rocks of the Calaveras Formation. If the present writer is correct in his interpretation of the stratigraphy of the Calaveras and the structure in this part of the area, the schist occurs in the core of an overturned anticline, the south flank of which exposes most of the thick section of Calaveras rocks (Upper Paleozoic). Thus, the schist probably represents the oldest unit found in the area of study.

* Deadwood Creek, unnamed on Plate 1, is located near the northeast corner of the quadrangle; it flows from east to west toward Concow Creek, more or less along the north edge of sec. 27, T.22 N., R. 4 E.

### Calaveras Formation

A thick series of metamorphosed, Upper Paleozoic sedimentary and volcanic rocks, representing deposition in the Cordilleran geosyncline, are widely distributed over the western slope of the Sierra Nevada. This series has been named the Calaveras Formation, and is well represented in the Oroville quadrangle by rocks that are similar lithologically to rocks mapped as Calaveras in other areas.

The name "Calaveras formation" first appeared in the literature in 1893. H. W. Turner (1893, p. 309) noted that the term was used for "all Paleozoic sedimentary rocks in the Sierra Nevada" by the U. S. Geological Survey. It was named for Calaveras County wherein these rocks are prominently displayed. In 1900, Lindgren (1900, pp. 1-2) subdivided the "Carboniferous group of the Colfax area, equivalent to the Calaveras formation of other folios" into five formational units; thus was the Calaveras elevated to group status. Taliaferro (1943, p. 280), recognizing the heterogeneous nature of the Calaveras, termed it "a catchall for all the Paleozoic rocks of the Sierra Nevada" having "no stratigraphic significance".

In the Oroville quadrangle, surface outcrops of the Calaveras Formation are restricted to the northeastern quarter of the area. Here they occur in a tightly folded belt, limited on the north and east by the edges of the mapped area, and on the south and west by a mantle of younger rocks. The general structural trend is northwest. The Calaveras is seen as abundant but discontinuous outcrops on the summits and sides of ridges in the higher parts of the area and is more or less continuously exposed along most of the larger streams.

Metasedimentary rocks—slate, sandstone, conglomerate, chert and limestone—and metavolcanic rocks—schistose and massive flows and pyroclastic rocks of varying composition—constitute the formation. Two distinctive lithologic units within the formation have been differentiated: the older is designated the *Hodapp Member*, and consists essentially of low-grade metamorphosed volcanic rocks of rather basic composition; the younger is the *Pentz Sandstone Member*, which is made up largely of sandstone and conglomerate, with some interbedded fragmental volcanic rocks. The term undifferentiated Calaveras is applied to the remainder of the formation, and includes beds chronologically, but not lithologically, equivalent to both Hodapp Member and Pentz Sandstone Member.

*Hodapp Member*

The name Hodapp Member is proposed for a succession of metamorphosed basic volcanic rocks which occur in the lower part of the Calaveras Formation. This unit is recognized in three separate belts which trend northwest across the northeastern portion of the quadrangle. All three belts are thought to represent essentially the same stratigraphic horizon, repeated by folding and, possibly, faulting. The two southernmost belts extend southeastward from beneath Tertiary strata near Nelson Bar and Lime Saddle. A third major belt lies along the lower part of Deadwood Creek and in the hills to the southeast. It has been intruded by two convergent masses of serpentine and metagabbro. Details of the original structures and stratigraphy of the Hodapp Member are excellently displayed along Hodapp Creek, the type locality (in secs. 5, 6, T. 21 N., R. 4 E.), and along the respective canyons of the West Branch (both north and south of Nelson Bar) and Concow Creek.

The Hodapp Member consists principally of schistose rocks derived from flows, tuff, and tuff-breccia of basic to intermediate composition. These rocks are characteristically light grayish-green or dark bluish-green. Chlorite schist, in places showing megascopically visible flakes of chlorite, is the dominant lithologic type, and in large part is thought to be the derivative of fine-grained tuff or tuffaceous shale. In places, however, nonschistose, massive rocks are found within the member which contain abundant, more or less evenly distributed, drawn-out amygdules of calcite. Such occurrences are interpreted as lava flows. At other localities, the volcanics may exhibit well defined, coarse fragmental structure, but because of the schistose character of most of these rocks, it is difficult to determine whether they represent original tuff-breccia, agglomerate, or autobrecciated flows. The strict lithologic homogeneity of the volcanic fragments and the dearth of non-volcanic debris in such occurrences appears to rule out the possibility that they originated as volcanic conglomerate. On the West Branch, north of Nelson Bar, a strongly sheared tuff-breccia or agglomerate occurs; individual "strung-out" fragments up to one foot in length are rich in calcite-filled amygdules. The fragments are set in a matrix of chlorite schist, the schistosity surfaces tending to curve around the clasts (Fig. 9). Rounded fragments of limestone, up to eight inches across, are occasionally found in this rock. On a small point of rock about one mile south of Gold Flat, an intensely sheared, grayish-green agglomerate or tuff-breccia crops out. The individual fragments, up to four inches in maximum dimension, are markedly flattened and drawn out, and contain abundant calcite-filled or chlorite-filled amygdules; limestone fragments are abundantly intermingled with the volcanic clasts.

In thin section most of the greenschists of the Hodapp Member are seen to differ little from those of the undifferentiated Calaveras Formation described below. They are essentially chlorite-albite-epidote schists, and are derivatives of basic to intermediate volcanic rocks. However, microcrystalline actinolite-albite-epidote chlorite schist, hand specimens of which are markedly similar to those of the chlorite schist, appears to be abundant in the northernmost belt of Hodapp strata. Uncommonly in this northern belt, metavolcanics have recrystallized to fine-grained, and even medium-grained, diorite-appearing rocks containing megascopically visible amphibole and plagioclase crystals. These coarser-grained variants occur as more or less equant or lenticular masses, rarely over a few feet in maximum dimension, apparently isolated within, and gradational to, microcrystalline greenschists. At these localities, parts of the metavolcanics have been markedly brecciated. The angular fragments in the breccia are separated by irregular veinlets of yellowish-green to greenish-white, microcrystalline, xenoblastic aggregates of epidote or clinozoisite. It is possible that such observed differences in the development of metamorphic minerals between the several parts of the Hodapp Member were caused by such factors as local variation in degree of deformation, in partial pressures of $CO_2$ and $H_2O$, and in the character of the original rock (e.g. chemical and mineralogical composition; average grain-size; fragmental versus non-fragmental types; and initial content of relatively unstable material, such as volcanic glass).


Figure 9. Sketch of sheared tuff-breccia or agglomerate, showing highly amygdaloidal blocks, or bombs. Hodapp Member. West branch of Feather River near Nelson Bar.

Dense, massive, slightly schistose, dark-bluish-gray or dark-bluish-green rocks are widespread in the Hodapp, but are much less abundant than the schistose varieties. Most of them are probably somewhat metamorphosed lava flows of basic to intermediate composition. A typical example, interpreted as being a metamorphosed basaltic or andesitic flow, is seen in a roadcut south of Gold Flat. Here, a massive dark-greenish-gray microcrystalline rock with locally concentrated calcite- or chlorite-filled amygdules occurs. It shows some incipient schistosity. Veinlets of epidote often rich in pyrite transect the rock locally. Under the microscope, the rock is seen to be very slightly porphyritic, with occasional slender phenocrysts of plagioclase set in a microcrystalline, felted groundmass. Medium oligoclase makes up approximately one-half of the rock (exclusive of the amygdules). Epidote, as small granules associated with minor clinozoisite, and sphene, in ragged, irregular patches, each constitute one-fifth of the total. The remaining 10 percent consists of chlorite. Amygdules occupy approximately one-fifth of the total volume, and are filled with calcite or, less frequently, chlorite.

Interbedded metasedimentary rocks in the Hodapp Member are confined to a few lenticular belts of black slate, chert and limestone. Where slate occurs, it is present in thin-bedded sequences alternating with fine-grained tuff. One small lens, eight feet thick, of rhythmically interbedded, thin-bedded chert and limestone lies in the metavolcanics about one-fourth mile north of Nelson Bar. Southwest of Gold Flat, a narrow, lenticular body of dark red chert occurs; the chert has a rough, ill-defined fracture-cleavage, and many of the cleavage surfaces are coated with a velvety film of fine-grained, dark-green chlorite. Along Concow Creek, north of the mouth of Deadwood Creek, coarse volcanic conglomerate is intercalated with the Hodapp Member, and apparently represents a local intraformational reworking of the member. The frequency of non-volcanic interbeds increases rapidly toward the southeast, and in the vicinity of Deer Peak, the metavolcanic rocks appear to lens out into, and interdigitate with, the metasedimentary strata of the undifferentiated Calaveras Formation. It is inferred from this that the eruptive centers which furnished the lavas and pyroclastic rocks of the Hodapp Member lay northwest of the present exposures and are probably buried beneath the Tertiary strata which now mantle the region. The widespread occurrence of marine metasediments within, and on strike with, the Hodapp suggests that the volcanic rocks themselves were emplaced in or near the sea. Definite pillow structure, which would tend to support this conclusion, was not found in these rocks by the writer.

The lateral extent of the Hodapp Member is rather limited. All three belts are covered at their respective northwest ends by flat-lying Tertiary volcanic and sedimentary rocks. The northernmost belt is sharply truncated on the southeast at the convergence of the two basic-ultrabasic intrusive masses. Mention has been made above of the gradual lensing out of the two southern belts toward the southeast.

The Hodapp Member is both underlain and overlain by slates of the undifferentiated Calaveras. Both contacts appear to be gradational through volcanic slates or through the gradually increasing frequency of metavolcanic interbeds in the metasediments. The Hodapp Member is thickest in the area north of Nelson Bar, where it attains a thickness of approximately 2700 feet. The maximum thickness of the belt south of Nelson Bar is about 1800 feet, while that of the northernmost belt is at least 1500 feet.

###### Pentz Sandstone Member

Two major belts of relatively coarse-grained sediments — sandstone and conglomerate — have been mapped separately in that part of the area otherwise dominated by the ubiquitous Calaveras slates and "greenstones". Because of the writer's structural interpretation and the lithologic similarity between the two belts they are regarded as correlative. The name Pentz Sandstone Member is applied to these rocks, since they crop out extensively east of the settlement of Pentz (secs. 19, 30, T. 21 N., R. 4 E.). In the vicinity of the type locality, they are exposed from Parish Camp and Glover Ridge southwestward to the lower part of Sawmill Ravine and Messilla Valley, and also appear intermittently from beneath Tertiary sediments for a distance of several miles up the canyon of Dry Creek. The second major belt extends northwestward from the upper part of Rich Gulch nearly to the top of the Tertiary-capped ridge north of Cape Horn. Several discontinuous, lenticular beds of conglomerate, similar to those in the Pentz Sandstone Member, are interbedded with the slates in Blair Ravine and south of Pingston Ravine. The structural position of these last-mentioned beds suggests that they are correlative with the Pentz Sandstone Member to the southwest.

The Pentz Sandstone Member at its type locality consists of interbedded sandstone and slate, with subordinate amounts of conglomerate, and small, widely separated masses of chert and limestone. Several hundred feet of volcanic sandstone, basaltic and andesitic tuff, lapilli tuff, and tuff-breccia lie near the middle of the exposed section between Pentz and Glover Ridge. Sheared argillaceous sandstone is the dominant lithologic type. It tends to be dark gray or black on fresh exposure, but soon weathers to shades of light gray or pale buff. In lower Sawmill Ravine, sandstone resting beneath Eocene sediments has been weathered to soft, claylike material which shows thin alternating bands of orange-yellow and brick-red as remnants of original thin-bedding. The sandstone is massive to thin-bedded, and often alternates with thin strata of black slate, similar to that which characterizes the undifferentiated Calaveras. Where thin-bedding occurs, individual beds may be as thin as a fraction of an inch, and, at times, near-rhythmic alternations of sandstone and slate are found. Graded bedding is well-developed at some localities, and convolute bedding occasionally occurs. The sandstone tends to be fine- to medium-grained, but where massive, it is usually coarse-grained and frequently grades into strongly sheared, fine-pebble conglomerate. The latter contains abundant pebbles of chert, older metavolcanic rocks, and angular chips of black slate.

Seen in thin-section, most of the sandstone is readily classified either as volcanic graywacke or lithic graywacke (cf. Gilbert in Williams, Turner, and Gilbert, 1954, pp. 297-304). A dark-colored semi-schistose argillaceous matrix, partly recrystallized to "sericite", chlorite, and sphene, constitutes from 15 to 50 percent of the rock. The grains are poorly sorted both with respect to size and to composition. They are dominantly subangular, but many angular and subrounded grains are present as well. Certain of the grains appear to be flattened and drawn out parallel to the incipient schistosity. Prominent constituents include unstable lithic fragments (15-50%; principally dense volcanics and slate in varying proportions), acid plagioclase or indeterminate, altered feldspar (5-35%), quartz (3-15%), augite (0-15%), detrital chert (3-10%), and detrital carbonate (0-10%).

Grayish-green andesitic and basaltic pyroclastics, with subordinate interbedded strata of volcanic sandstone, constitute an integral part of the Pentz Sandstone Member at the type locality. These rocks occur near the center of the exposed section and are interfingered with the predominant sedimentary strata. The two most important types present are lithic-crystal tuff and lapilli tuff; tuff-breccia occurs locally. Bedding is sometimes recognized by the presence of thin partings of black slate or slaty sandstone. The only megascopically prominent mineral constituents of the tuff are "saussuritized" plagioclase and augite, but neither of these are common. The predominant lapilli tuff is composed of subangular fragments, ranging from a few millimeters to one inch across, of porphyritic volcanic rocks, with scattered chips of black slate. Sorting is poor in most of the lapilli tuff and the fine- to coarse-grained tuff matrix is frequently gradational into the lapilli themselves.

A typical example of lithic-crystal lapilli tuff from a locality about one mile northeast of Pentz was selected for chemical analysis (Table 1). Microscope examination of this rock reveals a coarsely fragmental structure in which many angular to subangular porphyritic rock-fragments are set in a matrix of finely pulverized lithic and crystal grains. The porphyritic fragments contain phenocrysts (1-2 mm) of augite (25%) and thoroughly altered plagioclase (35%), and amygdules of chlorite (5%) set in a microcrystalline, allotriomorphic-granular groundmass (35%) of albite (?), clinozoisite, chlorite, and sphene. The analysis shows the rock to be of basaltic composition, with a comparatively high content of alumina. In this respect, it is comparable to analysed specimens of the porphyritic basalt at Glover Ridge and a flow in the Oregon City Formation. However, from certain other features of the analysis, normative composition, and oxide-ratios of this rock, it does not appear likely that it can be correlated on a chemical basis with either of the other two.

In the main northern belt, the Pentz Sandstone Member consists dominantly of strongly sheared pebble- and pebble-cobble conglomerate, interbedded with which are subordinate strata of sandstone and black slate. Dark-colored, dense chert and slate are abundant as pebbles and cobbles, although noteworthy quantities of aphanitic or porphyritic metavolcanics, chlorite schist, quartz, and black crystalline limestones are also common as clasts. The conglomerate is usually rather ill-sorted with respect to size; that containing a notable proportion of smaller pebbles is intensely sheared, and the pebbles have a distinctly flattened or "strung-out" shape parallel to the cleavage of the slaty matrix in which they rest. Where the conglomerate consists chiefly of cobbles, it has a tendency to be more massive and to lack any well-defined cleavage. It is noteworthy that the conglomerate in this northern belt coarsens markedly along strike from southeast to northwest. At the northwest end of the belt many beds of conglomerate consist dominantly of rounded cobbles, while southeast of Serpentine Point, few clasts coarser than small pebbles are found.

*Table 1. Chemical Analysis No. 3.**

| Analysis | | Calculation of Norms | |
|---|---|---|---|
| $SiO_2$ | 48.04 | Q | 2.82 |
| $Al_2O_3$ | 18.06 | or | 8.70 |
| FeO | 7.88 | ab | 15.87 |
| $Fe_2O_3$ | 3.02 | an | 38.63 |
| $TiO_2$ | .66 | ne | none |
| MnO | .14 | di | 7.20 |
| CaO | 10.03 | hy | 19.91 |
| MgO | 4.54 | ol | none |
| $K_2O$ | 1.38 | ap | 1.0 |
| $Na_2O$ | 1.77 | il | 1.27 |
| $H_2O$ (− 105°C) | .24 | mt | 4.61 |
| $H_2O$ (+ 105°C) | 3.42 | | |
| $CO_2$ | .25 | | |
| $P_2O_5$ | .40 | | |
| | 99.83 | | |

MgO:CaO** = 0.63
CaO:$Na_2O$** = 6.28
$Na_2O$:$K_2O$** = 1.94

* Analyst: W. H. Herdsman.
** Molecular ratio.

The main northern belt of the Pentz Sandstone Member is thickest at its northwestern end; the thickness progressively diminishes toward the southeast. The thickness at the junction of Concow Creek and the West Branch is 2300 feet. Southeast from here, the unit apparently interdigitates with finer-grained sandstone and slate of the undifferentiated Calaveras, and is no longer mappable beyond that point. Thin lenticular beds of conglomerate or of sandstone lithologically similar to those of the Pentz Sandstone Member occur intermittently to the east edge of the mapped area. As has been pointed out already, the conglomerate coarsens markedly toward the northwest. This, coupled with the aforementioned lensing-out toward the southeast, seems to justify the conclusion that the Pentz Sandstone Member, at least in the northern area, was derived from a source lying to the west. Unfortunately, the belt disappears beneath a thick capping of Tertiary sedimentary and volcanic rocks a short distance west of the point where it is transected by the West Branch.

The exposed thickness of the Pentz Sandstone Member in the type locality is at least 3000 feet. Due to the complex folding which prevails, the presence of additional strata cannot be readily demonstrated. The unit there is underlain by the undifferentiated Calaveras slates, and the contact, though not directly observed, is thought to be gradational. The next youngest beds are those of the Oregon City Formation, believed to be Jurassic in age. The nature of the contact is not fully established, but appears to be a marked angular unconformity. The northern belt of the Pentz Sandstone Member is in gradational contact with the slates of the Calaveras, which both underlie and overlie the unit. As indicated above, this belt passes laterally toward the southeast into the finer-grained sediments of the Calaveras.

The association of a well-defined facies of comparatively coarse-grained clastics with a sedimentary section otherwise dominated by pelitic types suggests that the region was one of tectonic instability during the period of deposition. The exact mode of derivation and transportation of the coarser sediments cannot be determined in the light of the present evidence, and it is probable that several different sets of sedimentary processes converged to produce the resultant deposits. For example, a part of the material may represent detritus derived from uplifted terrestrial source-areas, while another part may have been carried in from previously deposited sediments by submarine slumping and turbidity currents, processes not directly related to normal subaerial erosion. The lithology of the clasts composing the conglomerate suggests, on the whole, derivation of detritus from a terrane which in some ways resembled, and was as diverse as, that exposed at present.

##### *Undifferentiated Calaveras Formation*

The Calaveras Formation, except for the Hodapp Member and Pentz Sandstone Member, has not been differentiated. This course has been necessitated by the fact that both the Hodapp and Pentz Sandstone Members lens out into slates toward the southeast, and belts of slate with which they are in mutual contact merge as a single, more or less homogeneous unit. Thus the undifferentiated Calaveras undoubtedly contains time-equivalents of both members but they are not recognizable as such on a lithologic basis in the field. Where compatible with the scale of the map (Pl. 1), lenticular outcrops of chert, limestone, conglomerate, and volcanics are shown.

The predominant lithologic element of the Calaveras in this, as in other areas of the western Sierra Nevada, is slate. The slate is usually black in fresh exposures, but in weathered outcrops, such as typify most of the ridge-tops, it has become dark gray, light greenish-tan, light silvery-gray, or white. The black


Figure 10. Sheared sandstone and slate. Undifferentiated Calaveras Formation near Rich Gulch.

color of the slate is probably due to the presence of finely divided carbonaceous impurities. In a few places, the slate will leave a powdery black streak when drawn over the hand. Irregular patches of residual black carbonaceous (?) pigment are often seen in the lighter-colored, weathered slate. Various tints of red have been imparted where slate apparently containing some admixed volcanic detritus has been weathered. The cleavage-surfaces in fresh slate usually exhibit definite, though faint, luster. At many localities, however, the silky sheen of the phyllite-stage may be observed. The slate is commonly cross-fractured, and cleavage surfaces are irregular. At a few random localities, however, perfectly planar "papery" cleavage is developed. Pencil-slate is found along the axes of several folds.

In many parts of the section, strongly sheared argillaceous sandstone is interbedded with the slate, and is especially abundant at horizons adjacent to the Pentz Sandstone Member. Most of the sandstone is fine- to medium-grained and occurs as thin beds intercalated with slate. In places the bedding has a near-rhythmic aspect, but usually the sandstone appears as thin partings between thick strata of slate. The sandstone is invariably sheared more or less parallel to the cleavage of the enclosing slate. In Rich Gulch, individual sandstone beds have been sheared into lensoid masses, which appear to have been moved about as passive isolated elements within the more incompetent slate (Fig. 10). At a few localities the sandstone exhibits graded bedding, but more often such small-scale features have been obliterated by shearing.

As seen in thin section, the majority of the sandstone is lithic graywacke. It is typically dark gray, and some is nearly black because of an organic, argillaceous matrix. The presence of this matrix probably accounts for the apparent ease with which some of the sandstone has been sheared. Sorting of the grains with respect to size appears to have been slight. Besides the matrix, the most abundant constituents are grains of detrital chert and slate, while quartz and feldspar are markedly subordinate. Most of the grains are angular to subangular. Those having some elongation, in particular the chips of slate, show a strong preferred orientation parallel to the plane of shearing, and in some cases, the elongation appears to have been accentuated by the shearing movements. Most of the microcrystalline matrix is indeterminate, but such minerals as "sericite", chlorite, sphene, and tremolite may frequently be identified as products of recrystallization of the original argillaceous material.

Thin beds of strongly sheared pebble-conglomerate are interbedded with the slate at several localities. The conglomerate is, on the whole, very much like that previously described as part of the Pentz Sandstone Member.

Volcanism was not limited to the periods during which the Hodapp and Pentz Sandstone Members were deposited, but continued intermittently throughout the time of deposition of the Calaveras Formation as it is represented in the Oroville quadrangle. Several lenticular bodies of metavolcanic rock appear on the geologic map in areas otherwise mapped as slate. These include partly metamorphosed flows and pyroclastic rocks of basaltic, andesitic, and dacitic composition. Perhaps of even greater importance with regard to volume of material, however, are innumerable lenticular metavolcanic strata, too small to map, which are intercalated with the slate at many localities. These are not readily apparent where outcrops are poor, but are especially conspicuous in the larger stream canyons and ravines. The most common type of metavolcanic rock occurring in the undifferentiated Calaveras is greenish-gray, fine-grained schist of low metamorphic grade. This rock evidently represents, in part, fine-grained intermediate to basic tuff or tuffaceous shale. These meta-tuffs may be massive or thin-bedded. Thin-bedded sequences of alternating black slate and greenschist are often encountered (Fig. 11). Contacts between the greenschist and slate may be sharply defined, but more often are vague and gradational. Slate adjacent to volcanic strata is frequently harder and less easily cleaved than normal slate and is tinted green. Some schistose lapilli tuff, with lapilli averaging one-quarter to one-half inch, and a few schistose to massive flows have been recognized. The flows have been distinguished by their content of evenly distributed amygdules, which may be filled with quartz, calcite, or chlorite. Massive or poorly cleaved, hard, green aphanitic rocks which are interbedded with the slate at many localities are also thought to be derivatives of basic volcanic rocks or tuffaceous shale.

Figure 11. Alternating black slate and greenschist. Undifferentiated Calaveras Formation, west branch of Feather River near Oro-Concow Road.

Chlorite-albite-epidote schist is the dominant rock type seen in thin section. Schistosity is often made apparent by the segregation of groups of certain minerals into indefinite laminae. The foliation is sometimes acutely folded. The mineral assemblage is dominated by chlorite, in minute flakes, and untwinned albite, generally present as very fine-grained, xenomorphic aggregates, but sometimes as long, thin subhedral laths. Epidote minerals, usually represented by clinozoisite and minor yellow epidote, are typically present, though always subordinate to chlorite or albite. They most often occur as small, subhedral prisms scattered throughout the rock. Calcite occurs as ragged, irregular masses up to 5 mm across or as veinlets in most of the schist, and is rather abundant in several of the sections examined. Sphene is invariably present in the schist, and is commonly arranged in long, ragged trains, paralleling and accentuating the schistosity. Minerals often occurring in minor quantity include "sericite", chromite, hematite, magnetite, and pumpellyite (?). In a greenschist from Rich Gulch, very pale green actinolite, rather than chlorite, is the dominant ferromagnesian mineral, although some chlorite, concentrated in irregular clots, is present. The mineralogy is otherwise similar to that of the chlorite-rich types. The greenschists are thought to be products of low-grade metamorphism of basic to intermediate volcanic rocks and tuffaceous sediments. In view of the relatively weak nature of the metamorphism which the rocks have undergone, it seems unlikely that they were ever much coarser-grained than they are at present. Relict textures have not been observed, either in hand specimens or in thin sections. Some fragmental structure is seen in well-exposed outcrops, however, and, if it is original, might well indicate that the schists have been derived from pyroclastic rocks. The multiple interlayering of thin beds of greenschist and slate suggests the intermittent addition of fragmental volcanic material (either by volcanic or sedimentary processes or both) to a basin otherwise receiving normal nonvolcanic sediments (clay, silt, etc.).

Trending northwest over the southern end of Jordan Hill is a belt of dense, more or less massive, locally thin-bedded, greenish-gray rock which is believed to be a slightly metamorphosed basaltic or andesitic tuff. Euhedral crystals or crystal-fragments of indeterminate, altered plagioclase (30%) and diopsidic augite (10%) may be seen in thin section. These are accompanied by fragments of cryptocrystalline or microcrystalline, nearly opaque rocks (10%), in part clearly of volcanic origin. The fragments are held in a microcrystalline aggregate of partly recrystallized minerals. The plagioclase is thoroughly altered to albite (?), calcite and "sericite". Some crystals of the augite are partly rimmed by acicular actinolite. Much of the matrix is indeterminate, even under high power, but those components which can be recognized include albite (?), clinozoisite, epidote, chlorite, sphene, and pumpellyite (?). Disseminated throughout the whole are minute needle-like prisms of actinolite. This sequence of pyroclastics lies but a few hundred feet stratigraphically above the top of the main northern belt of Pentz sandstone and thus may be correlative with the basic pyroclastic rocks which are intercalated with the Pentz Sandstone Member at its type locality.

A massive, light greenish-gray, porphyritic keratophyre is intercalated with Calaveras slate in Pingston Ravine. Under the microscope, the rock is seen to contain phenocrysts of unaltered albite ($An_0$—$An_5$) and a few anhedral phenocrysts of partly uralitized augite. They are set in a trachytic to pilotaxitic groundmass consisting, in large part, of albite microlites. Minute grains of epidote, clinozoisite, sphene, and ilmenite (?) are disseminated throughout the rock. A few small spherical amygdules of chlorite and granular quartz may be seen.

Quartz-bearing volcanic rocks appear to be exceptional in the bedrock terrane of the Oroville quadrangle. The only occurrence of such rocks known to the writer are the lenticular dacite flows (?) which are intercalated with the undifferentiated Calaveras formation on Hump Hill and just south in the canyon of Grizzly Creek. In hand specimen, the rock is typically medium-bluish-gray to very dark-gray, massive, and porphyritic. Sub-equidimensional phenocrysts of glassy quartz and plagioclase, set in an indeterminate, microcrystalline groundmass, are plainly visible. Under the microscope, the rock is seen to be slightly brecciated. Fragments of both phenocrysts and groundmass rest in narrow, vein-like stringers of dusty, nearly opaque, largely cryptocrystalline material. Sphene (?) and clinozoisite (?) are apparently the chief constituents of these veinlets. In the unbrecciated portion of the rock, euhedral phenocrysts of quartz, plagioclase, and minor biotite and orthoclase (?) together constitute about 15 percent. These are set in a microcrystalline, allotriomorphic granular groundmass dominated by quartz and feldspar and containing scattered crystals of clinozoisite, biotite, epidote, and scattered euhedral microlites of feldspar.

Isolated, lensoid masses of bedded chert occur at many horizons throughout the Calaveras section. Most commonly the rock is light-colored—white, light gray, light grayish-green—but at many localities is red, dark green, or black. Bedding, where present, is always distinct and is often rhythmic in beds ranging from about 2 inches to ½ inch in thickness. The chert is generally microcrystalline, but occasionally exhibits fine-grained crystallobalastic texture where it has been recrystallized. Thus, the masses of metachert enclosed within the metavolcanic belt north of Deadwood Creek show a fine-grained, sugary, quartz-fabric and the development of minute muscovite flakes on incipient schistosity surfaces. Much of the chert has been markedly sheared, and irregular cleavage has been superimposed on original bedding to produce a "bundle" of small lensoid sheets. At a few localities, the chert has been brecciated and recemented by microcrystalline quartz. Many of the chert masses grade insensibly through slaty chert and siliceous slate to normal slate, apparently free from notable siliceous content. Many of the chert bodies in the Calaveras have a close spatial relationship to metavolcanics. For example, on the West Branch near the mouth of Rich Gulch, massive light gray chert is interbedded with contorted chlorite schist; in any one outcrop one or the other type may predominate. Where the chert is dominant the schist appears as contorted beds or veinlets throughout the chert; on the other hand, large, white, rounded "pods" of white chert may occur in the dominant schist, with the schistosity curving around the clasts.

Microscopically, the chert often shows a marked variation in grain-size, even within one thin section. The variants are arranged as parallel, lenticular lamellae. Quartz dominates the simple mineral assemblage, and occurs in a granoblastic mosaic of slightly elongated xenomorphic crystals which rarely exceed 0.1 mm in length. White mica, which may locally form 15 percent of the rock, occurs as isolated, minute, euhedral plates or as aggregates of plates. These show a strong preferred orientation parallel to the laminae. Veinlets of late quartz often transect the rock at right angles to the schistosity.

Limestone occurs at many localities in the Calaveras, but few of the bodies are large enough to map on the present scale. Of these, several large lenticular masses lie interbedded with the slates east and south of Parish Camp, one lies east of Nelson Bar, and small bodies occur north of Nelson Bar and southeast of Lime Saddle, respectively. The rock is light gray on weathered surfaces, but when freshly fractured, is dark gray to black. The limestone is usually dense, but some recrystallization to coarse-grained calcite has occurred locally. Shearing, whose effects have been accentuated by differential weathering, is often indicated, and, where present, trends parallel to the cleavage of the enclosing slate. Recognizable bedding was observed at only one locality; on the Upper Miocene Canal, two miles north of Cape Horn, thin-bedded limestone carries rhythmically spaced partings of gray chert. Small "pods" of limestone ranging from a few inches to several feet in maximum dimension occur at many localities in the slate. Differential weathering of the limestone has produced rough, hackly surfaces and miniature, stalactite-lined caverns. Where large masses of limestone lie on steep hillsides near-vertical cliffs, up to 150 feet in height, are often observed. This feature is perhaps indicative of the major role of the mechanical, rather than chemical, side of weathering at the present time. Most of the limestone lacks any obvious organic structures, but some is locally rich in fragmentary crinoid stems. Several small, indeterminate gastropods were collected from limestone east of Nelson Bar, and a few specimens of coral were found in the large lens east of Parish Camp.

Under the microscope, most of the limestone is seen to conist of a very fine-grained granoblastic aggregate of anhedral calcite. Occasional thin lenses of coarse-grained calcite occur amidst the finer-grained aggregate. A few percent of detrital quartz or chert may be present as angular grains. Stringers of opaque, carbonaceous (?) material are arranged along shear-planes.

Samples from the two largest limestone lenses in the area were analysed chemically. The analyses are listed below (Table 2).

*Table 2. Partial chemical analyses* of limestone samples.*

| | No. 1** | No. 2** |
|---|---|---|
| CaO | 53.96 | 53.08 |
| MgO | 1.20 | .60 |
| $Al_2O_3$ | .23 | .39 |
| $SiO_2$ | .28 | 2.22 |
| $Fe_2O_3$ | .11 | .11 |
| $P_2O_5$ | .02 | .01 |

* Analyst: Martin P. Quist for Abbot A. Hanks, Inc., San Francisco.
** No. 1: Center of south margin of 200-foot by 1,000-foot lens, NW¼ NW¼ Sec. 8, T21N, R4E, M.D.B.M.
No. 2: Near southeast end of 400-foot by 800-foot lens, NW¼ NE¼ SW¼ Sec. 17, T21N, R4E, M.D.B.M.

The only diagnostic fossils found in the Calaveras Formation by the writer came from a large limestone lens lying east and slightly south of Parish Camp (Locality no. 1). The specimens were submitted to Dr. Ralph L. Langenheim, who has furnished the following statement * regarding them.

> The specimens are tetracorals with approximately 50 septa, a columella, and possibly with a dissepimentarium. Their age is probably Late Paleozoic and is likely to be Permian. Fragments of crinoid stems are present in the insoluble residue.

The limestone in which the fossils occur is approximately 3000 feet stratigraphically below the base of the Pentz Sandstone Member and is thus in the lower one-third of the Calaveras Formation as it is exposed in the Oroville quadrangle. Whitney (1895, pp. 209-210) collected fossils from a limestone near Pentz. He stated:

> About one and a half miles northeast of Pence's [Pentz] are large outcrops of limestone interstratified with the auriferous slates. . . . The best specimens were obtained near the bend of a small canyon called "West Branch". . . . The fossils found in these limestones, although imperfect, are sufficient to identify them as of the same age as those of Bass's ranch*, which are pronounced by Mr. Meek to be Carboniferous. *Productus semireticulatus* and *Spirifer lineatus* were recognized by Mr. Gabb. . . .

* Written communication, 1955.

Whitney apparently referred to the same limestone body from which the writer collected the corals noted above.

The Calaveras Formation was generally considered to be of Mississippian age until 1951, when Taliaferro published the following statement regarding the unit (p. 119):

> In that part of the Sierra Nevada extending from the American River southward to the Merced River the oldest known rocks are Paleozoic. These consist of slates, sandstones, conglomerates, limestones, cherts and volcanics that have been folded at least twice and intruded by igneous rocks. These are called the Calaveras group and undoubtedly consist of rocks of several ages. Just how much of the Paleozoic is represented is unknown but it is known that sediments and volcanics ranging from Mississippian (Lower Carboniferous) age through Upper Permian are represented. In all previous publications the Calaveras has been stated to be of Mississippian age. However, in the summer of 1948 a party of students working under the direction of the writer found fossils of Upper Permian age in "Calaveras" limestones a few miles east of the eastern boundary of Sacramento County. In other localities Lower Carboniferous fossils have been found in "Calaveras" limestones. Thus the "Calaveras group" actually is a heterogeneous assemblage of rocks of Upper Paleozoic age. In fact, it may contain rocks of Lower Paleozoic age also.

A few writers have subdivided the Calaveras Formation in various parts of the Sierra Nevada. Mention has already been made of Lindgren's fivefold subdivision of the Calaveras of the Colfax area. Ferguson and Gannett (1932, pp. 6-12), working in the Alleghany gold district south of Downieville, utilized Lindgren's units and recognized two additional formations. Diller (1892, pp. 374-376; 1908, pp. 20-30) differentiated the Calaveras strata in the Taylorsville region, and recognized three formations there. Undoubtedly the Calaveras Formation as it is mapped in the Oroville quadrangle is in part correlative with the Calaveras of some previously studied areas. However, to what extent the various subdivisions recognized in other areas can be applied to these strata is not known. Conversely, because of the gross lenticularity of the several subdivisions of the Calaveras in the Oroville quadrangle, and because of the metamorphism, structural complications, discontinuity of regional outcrops, and paucity of fossils displayed by the Calaveras rocks throughout the Sierra, it appears unlikely that any of the members proposed by the writer can be recognized in other areas.

The thickness of the Calaveras Formation in the Oroville quadrangle is approximately 11,000 feet. The Calaveras is underlain at the northeastern corner of the area by schistose metavolcanic rocks of possibly

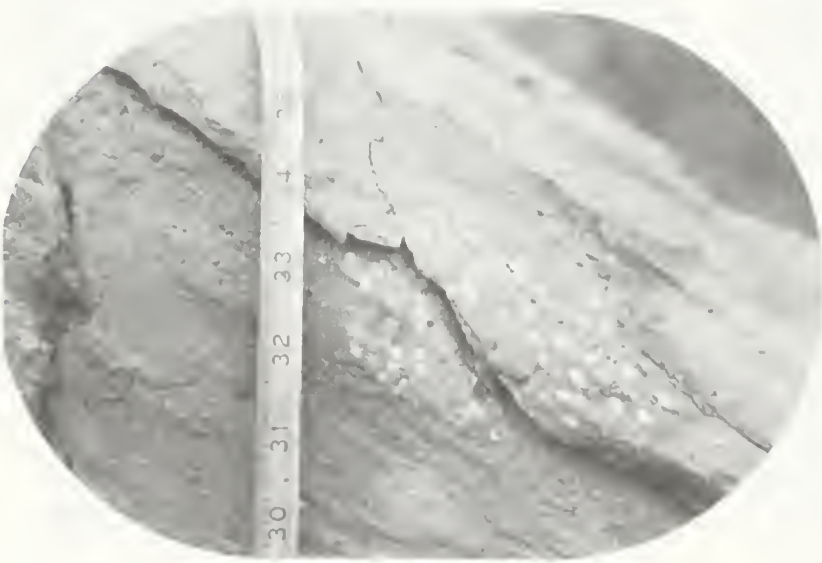
* Bass's Ranch, about 15 mi. NE of Shasta City, Shasta County, California.


Figure 12 (left). Fracture cleavage in thin-bedded tuff or volcanic sandstone. Oregon City Formation. Campbell Flat.

Figure 13 (below). Sheared tuff-breccia. Oregon City Formation. Campbell Flat.

Figure 14 (below, right). Amygdaloidal blocks in tuff-breccia. Oregon City Formation. East bank of Feather River about a mile north of Oroville.

Figure 15 (below). Amygdaloidal block in sheared tuff-breccia. Oregon City Formation, Campbell Flat.



late Paleozoic age. The contact there is not exposed, but appears to be rather well-defined and may represent a fault. The oldest rocks overlying the Calaveras are the volcanics and volcanic sediments of the Oregon City Formation. The contact is apparently a sharp angular unconformity, but because the structural relationships in the immediate vicinity are not clearly understood, this is not certain.

In summary, the Calaveras Formation as it is exposed in the Oroville quadrangle is a thick succession of sedimentary and volcanic rocks which have been subjected to low-grade regional metamorphism. The lithology of the Calaveras is dominated by carbonaceous slate and phyllite, sheared graywacke and graywacke conglomerate, and basic to intermediate extrusive volcanic rocks (at least some of which are members of the spilite-keratophyre association). Less abundant but widespread types include bedded chert, siliceous slate, tuffaceous (?) slate, and carbonaceous limestone. Thus, the lithologic assemblage found in the Calaveras Formation of this area has much in common with the association which is often cited as typifying geosynclinal deposits as a whole (Bailey, 1936; Jones, 1938; Eardley, 1947; Knopf, 1948; Kay, 1951).

The thick sequence of sedimentary and volcanic strata included in the Calaveras Formation was deposited in the western portion of the Paleozoic Cordilleran geosyncline. This part of the geosyncline was termed the "Pacific trough" by Eardley (1947, p. 309). Kay (1947, pp. 1291-1292) proposed the term "Fraser belt" for the rocks deposited in this part of the geosyncline. Eardley (1947) has discussed the various aspects of the Paleozoic Cordilleran geosyncline and the orogenic movements related to it, and has postulated a volcanic island arc system along, or just west of, the present Pacific coastline during the Paleozoic. The Calaveras Formation, as it occurs in this area and in other parts of the Sierra, seems to typify the close association of volcanic rocks and geosynclinal sediments which has long been recognized. The type of geosyncline in which such an association occurs has been termed an eugeosyncline (Kay, 1947, p. 1291; 1951, pp. 32-33).

The sedimentation and volcanism which had combined to form rhe deposits now embraced by the Calaveras Formation were brought to a close by the collapse of the geosyncline at or near the end of the Paleozoic. The available evidence indicates that folding, perhaps intense, took place at that time. To what extent the involved rocks were affected by metamorphism at that time is not clear, since the effects have been masked by those produced by a later orogeny—the Nevadan revolution. The contrast in degree of metamorphism between the Paleozoic rocks and the Mesozoic rocks may well indicate an earlier metamorphism, although some of the differences observed might be explained as the result of differences in stratigraphic position.

### Oregon City Formation

The name *Oregon City Formation* is proposed for a sequence of extrusive volcanic and volcanic-sedimentary rocks which has been mapped over much of the southeastern part of the area. Oregon City, the type locality, is in sec. 16, T. 20 N., R. 4 E. The available evidence indicates that at least a part, if not all, of these rocks are of Middle Jurassic age. The formation includes a wide variety of intermediate to basic pyroclastic rocks and flows and large quantities of volcanic-sedimentary rocks of similar composition. These rocks typify the term "greenstone" as used for green metavolcanic rocks of intermediate to basic composition.

By far the best exposures of the Oregon City Formation lie in the canyon of the Feather River, north and east of Oroville. The river has been cut almost entirely in bedrock, and many parts of the canyon are characterized by a broad stream-cut bench behind the present riverbank on which the greenstones are well exposed. (Fig. 7) North of the river, discontinuous outcrops extend for eight and one-half miles to Red Hill and Rocky Peak. Within the norrhern part of the outcrop area, the formation is conspicuously exposed in the vicinity of Oregon City, the type locality, and at Cherokee, where a pre-Miocene stream channel has been exhumed by erosion and mining operations. South of the Feather River, fresh outcrops of the formation are sporadic, and much of the area has been covered by Quaternary sediments. The westernmost outcrop of the Oregon City Formation lies in Thompson Flat, at the southern base of South Table Mountain.

Pyroclastic rocks—tuff-breccia, tuff, and perhaps agglomerate—and their epiclastic derivatives—volcanic sandstone and volcanic conglomerate—characterize the Oregon City Formation. Lava flows are an interesting but subordinate component. These rocks are of basaltic and andesitic composition, and are usually light grayish-green, greenish-gray, or dark green when fresh. When weathered, however, they alter to various shades of red, yellow, or, under extreme conditions, white. Except where they have been weathered, they are extremely well indurated.

Tuff makes up a major part of the Oregon City Formation. Much is massive, but some bedded types occur. Bedding may be manifested by variations in grain-size, by concentration of dark minerals along bedding planes, or sometimes by thin partings of slate. Small-scale cross-bedding and slump-bedding are sometimes observed, indicating that at least a part of the pyroclastic material was water-deposited. "Saussuritized" plagioclase, augite, and lithic fragments are the principal constituents recognized in hand specimens. The tuff varies from extremely fine to coarse-grained. Angular lapilli of porphyritic volcanic rocks are often present, and in many places the tuff grades into lapilli tuff. The finer-grained tuff, as well as some of the breccia, may possess a well-defined fracture cleavage (Figs. 12, 13), but true schistosity was observed at relatively few points. In general, the rocks in the northernmost part of the outcrop area appear to have been deformed more than those to the south. Under the microscope the tuff consists essentially of angular to subangular fragments of microcrystalline or porphyritic volcanic rocks, partly or wholly altered plagioclase, and relatively fresh augite. These are held in a subordinate, microcrystalline, largely indeterminate matrix which may include chlorite as a principal constituent. The larger lithic chips commonly show trachytic texture and frequently carry minute amygdules. Veinlets filled with secondary minerals such as clinozoisite commonly transect the rock. A textural feature thought to be diagnostic of pyroclastic (rather than epiclastic) origin is the abundance in some of the tuff of sharply angular splinters of the various components.

Certainly the most striking rocks of the Oregon City Formation are the thick accumulations of coarser volcanic ejecta with which the tuff is intimately associated. Lapilli tuff and coarse tuff-breccia occur at many horizons in the section. These are usually very ill-sorted with respect to size of fragments, and there may be all gradations into the tuffaceous matrix. The fragments in both types, up to 2½ feet across in the tuff-breccias, are angular to subangular and may often be highly amygdaloidal (Fig. 15). Spheroidal or ellipsoidal amygdules of white quartz, as much as one-half inch across, are common. Fillings of calcite or of chlorite are less frequently encountered. Most of the fragments are porphyritic, and phenocrysts of augite and "saussuritized" plagioclase are recognizable in many of these. Unlike the associated tuff, units of the coarser pyroclastic rocks seldom exhibit internal stratification. Where bedding does occur, it is rarely well-defined. In relatively few places can shearing be recognized in these rocks; more often they are massive in all respects except for the presence of several sets of widely spaced joints. The writer is of the opinion that the tuff-breccia and lapilli tuff may have been emplaced as volcanic mudflows. Certain of their features, as seen in the field, bring to mind the mudflows of the Tuscan and Mehrten Formations (Tertiary). The overall lack of sorting and internal stratification, the angular or subangular shapes of the blocks, and the apparent wide lateral extent of the deposits are all suggestive of such a mode of origin.

In thin section, all of the blocks and lapilli from the coarser pyroclastics are seen to consist of non-fragmental volcanic rocks, and of these, porphyritic types far outweigh the non-porphyritic or sparingly porphyritic varieties. Some of the porphyritic types are in part glomero-porphyritic. The groundmass is usually microcrystalline with a felted or, less often, pilotaxitic texture. Euhedral to subhedral phenocrysts of rather fresh augite are rarely absent and, in some specimens, may constitute as much as 35 percent of the rock. Infrequently, the augite shows some incipient uralitization and chloritization. Plagioclase phenocrysts, in part or totally altered, are commonly present, but in most rocks are quite subordinate to those of augite. On the other hand, microlites of plagioclase are abundant in the groundmass of most specimens, and in some cases total 40 percent of the rock. In most instances, alteration of the feldspar appears to have been of the "saussuritic" type, indicating that the original feldspar was somewhat calcic. In some specimens, however, the feldspar does not appear to have been appreciably altered, and is of rather sodic composition. The groundmass in most specimens has a dusty, partly opaque appearance. While much of it is indeterminate, some minerals can be identified. These include feldspar, chlorite, sphene, and epidote. Clinozoisite often occurs as small, isolated granules, and sometimes may be present in considerable quantity. Few of the fragments are totally without amygdules, and many are highly amygduloidal. Filling the amygdules, either in combination or separately, are chlorite, quartz and calcite, and, less commonly, epidote, clinozoisite, or albite. The blocks and lapilli are largely of basalt and andesite, but some rocks having keratophyric and spilitic affinities may also be present.

Flows are intercalated with the pyroclastic rocks at many localities. Poorly developed flow-banding was observed in a few outcrops, but more often the flows are massive, being of uniform granularity and color. They tend to be hard and aphanitic or microcrystalline, and a great many contain abundant quartz- or calcite-filled amygdules. They are markedly similar to the fragments found in the associated tuff-breccia. In places, porphyritic flows with abundant augite phenocrysts occur. Along the Feather River, near Sycamore Hill, contiguous flows make up several hundred feet of section. One of these exhibits well-defined pillow-structure. The individual spheroids are amygdaloidal and have diameters of two or three feet; they are separated by thin layers of pale-green, thinly laminated chert.

A fine-grained, slightly porphyritic flow (?) from the schoolhouse at Oregon City was analyzed chemically, and the results, with normative composition and certain of the oxide-ratios, are presented in Table 3. In thin section, this rock is seen to be dominantly fine-grained, with an intersertal texture. The presence of scattered crystals of slightly larger size than the rest lends a somewhat porphyritic aspect to the whole. The principal minerals are sodic plagioclase ($An_{10}$-$An_{13}$; 50-55%), diopsidic augite (30%), and chlorite (10-15%). Most of the plagioclase occurs in nearly euhedral, elongate crystals, whereas the augite is euhedral or slightly subhedral. Chlorite fills occasional small amygdules, but more often is present as the intersertal material between the finer-grained plagioclase

Figure 16. Jointed tuff-breccia. Oregon City Formation, Feather River, 1 mile north of Oroville.

Figure 17. Banded volcanic conglomerate and volcanic sandstone. Oregon City Formation, Feather River near Morris Ravine.

*Table 3. Chemical Analysis No. 2.**

| Analysis | | Calculation of Norms | |
|---|---|---|---|
| $SiO_2$ | 49.85 | Q | none |
| $Al_2O_3$ | 17.23 | or | 2.88 |
| FeO | 7.97 | ab | 35.25 |
| $Fe_2O_3$ | 1.43 | an | 28.47 |
| $TiO_2$ | .62 | ne | none |
| MnO | .10 | di | 13.49 |
| CaO | 8.72 | hy | 1.17 |
| MgO | 6.08 | ol | 15.33 |
| $K_2O$ | .48 | ap | none |
| $Na_2O$ | 4.03 | il | 1.26 |
| $H_2O$ (− 105°C) | .36 | mt | 2.16 |
| $H_2O$ (+ 105°C) | 3.12 | | |
| $CO_2$ | .03 | | |
| $P_2O_5$ | .06 | | |
| | 100.08 | | |

MgO:CaO** = 0.98
CaO:$Na_2O$** = 2.40
$Na_2O$:$K_2O$** = 12.72

* Analyst: W. H. Herdsmon.
** Molecular ratio.

laths. The rock contains about 5 percent of sphene. Epidote, "sericite", clinozoisite, and prehnite are very minor constituents.

The chemical analysis (no. 2) is that of a basalt although the alumina content is somewhat higher than for most basalts. The analysis is similar to those of some of the late Tertiary olivine basalts of the Cascades, and is particularly like one reported by Thayer (1937, p. 1622, analysis no. 4) for an olivine basalt from the north-central Cascades in Oregon. The rather sodic composition of the plagioclase, the relatively high values for $Na_2O$ and $Na_2O$:$K_2O$, and the low CaO:$Na_2O$ ratio suggest that the rock may have spilitic affinities, although the alumina content is well above that given for the average spilite by Sundius (1930, p. 9). Also noteworthy is the rather close agreement between certain features of the chemical analysis, normative composition, and oxide-ratios of this rock and those of a specimen of the porphyritic basalt at Glover Ridge. This relationship suggests that the two rocks and the units that contain them may be correlative. The rocks at Glover Ridge are thought to have been emplaced as a shallow intrusive mass and possibly as a volcanic neck. If such is the case, it may be that this eruptive center furnished at least part of the volcanic material now found in the Oregon City Formation.

Thick units of volcanic sandstone and volcanic conglomerate are frequently intercalated with the pyroclastic rocks, and together constitute a considerable part of the formation. They have much the same composition as their igneous counterparts, differing only in fabric. The sandstone evidently consists of material directly reworked from the pyroclastic deposits without much addition of foreign debris and without appreciable rounding of the detrital grains. Thus, considerable difficulty is often had in distinguishing between the two types in hand specimens, especially where the finer-grained varieties are encountered. It is probable that all transitions from tuff to volcanic sandstone exist among these rocks. It is likely that most of the finer-grained clastics interbedded with conglomerate or carrying some pebbly stringers are actually volcanic sandstone. Bedding may be indicative of an epiclastic rock, although tuffs originating in certain ways might also be expected to show some bedding. A distinction between pyroclastic and epiclastic types in the coarser-grained varieties is less difficult. In all probability many or all of the coarser rocks having rounded or subrounded clasts are volcanic conglomerate, although some agglomerate might also be present in the formation. The pebbles and cobbles consist essentially of the same rock types as are present in the tuff-breccia and lapilli tuff, along with occasional non-volcanic rocks such as chert. Though these rocks are rather ill-sorted with regard to size of clasts, they usually exhibit some degree of bedding (Fig. 17), a feature rarely observed in the tuff-breccia.

The Oregon City Formation is underlain by the Calaveras Formation. The exact nature of the contact is not clear because of the structural complexity which exists where the two units are in contact. However, it appears quite likely that an angular unconformity, perhaps severe, separates them. The Oregon City is overlain conformably by the Monte de Oro Formation. The contact is best seen on the west flank of the Monte de Oro syncline. Here, massive coarse-grained pyroclastic rocks of the Oregon City formation grade into and interdigitate with bedded volcanic sandstones of the lower part of the Monte de Oro Formation.

The greatest known thickness of the Oregon City is approximately 3200 feet, where the formation is exposed in Morris Ravine on the west limb of the Monte de Oro syncline. The base of the formation is not exposed there, however, so that a much greater thickness may actually exist. No accurate figure can be given for the thickness in the northern part of the area because of the uncertainties which exist regarding the structure there. It is probable, however, that the thickness is of the same order of magnitude as that found in Morris Ravine.

Mention has been made above of the transitional contact between the Oregon City Formation and the overlying Monte de Oro beds. This relationship suggests that at least the uppermost part, if not the whole, of the Oregon City Formation is of the same general age as the Monte de Oro, i.e. Middle Jurassic. The Oregon City Formation is believed to represent a single episode of volcanism, characterized by discontinuous but closely spaced eruptions. There appear to be no significant differences in bulk lithology in any part of the formation. No breaks representing normal, non-volcanic sedimentation are known, nor can volcanic products other than the intermediate to basic types which characterize the Oregon City be found. Thus if the uppermost part of the Oregon City Formation is actually Middle Jurassic, it would seem justifiable to assume that the remainder of the formation is Jurassic as well, until such evidence as may be found proves otherwise.*

### Monte de Oro Formation

The only bedrock strata in the Oroville quadrangle definitely dated as Mesozoic are those of the Monte de Oro Formation. This formation consists of dark-colored, slightly sheared, well-indurated sandstone, siltstone and conglomerate together with some slate. The lithology is in marked contrast to the thick volcanic sequence of the underlying Oregon City Formation. The Monte de Oro was named and first described by H. W. Turner (1896, p. 549). He stated:

> The slates of the area are very similar to those of the Mariposa formation from known areas of which they are, however, widely separated. This plant bearing series may be called the Monte de Oro formation, from the point so named that lies just north.

Brief references to these beds appeared in the literature from time to time in connection with the fossil flora preserved therein (cf. Fontaine, 1900; Knowlton, 1910). Diller (1908a, pp. 389-390) devoted several pages to the Monte de Oro, and his discussion was the most complete of any published up to that time. Re-

* In 1955, since completion of this manuscript, a single ammonite was collected by the writer (acting on the advice of Professor C. M. Gilbert) from rocks mapped as Oregon City Formation on the north bank of the Feather River (east edge of sec. 4, T. 19 N., R. 4 E.; Stanford Univ. Mus. Paleontology locality no. 9063). This specimen was subsequently identified by Professor S. W. Muller of Stanford University as *Perisphinctes* sp. Professor Muller, in a letter dated May 11, 1956, stated that "I would venture a guess that it is a *Perisphinctes* in the broadest sense and is probably of Late Jurassic (Oxfordian) age. Please bear in mind that *Perisphinctes*-like forms also occur in the next higher Kimmeridgian stage." On the basis of this determination the Oregon City Formation probably is, at least in part, Late Jurassic.

If, as is suggested by this find, the Oregon City is actually of Oxfordian age, it seems likely that the formation is correlative with the Logtown Ridge Formation, mapped farther south in the Sierran foothills by various workers. The Logtown Ridge strata, to which the rocks of the Oregon City bear a close resemblance, are, at the type locality on the Cosumnes River, Upper Jurassic (i.e. middle Callovian (?) to upper Oxfordian (?); Imlay, 1961, p. D-6).

garding the lithology, stratigraphy, and structure of the formation, he wrote:

> The conglomerates of the plant beds contain many pebbles like those of the tuffs . . . . There are in the same region, at a different horizon, other masses of fossiliferous tuffaceous sandstone interbedded with the regular tuffs. Mr. Storrs recently discovered a small one on the north bank of the Feather River, one-fourth mile west of the mouth of Morris Ravine, and the fossil shells it contains are the same as those of the Banner Mine area. The bulk of the evidence supports the view that the deposition of the plant beds at Oroville occurred during a quiet interval in the time of volcanic activity, but it is not yet certain that they are not later and occupy a syncline folded into the underlying volcanics . . . . The fact that the conglomerates and sandstones are mainly along the borders, with slates prevailing in the middle of the area, suggests that the mass may be an apprest syncline.

The most recent discussion of the formation is by Taliaferro (1942, pp. 90-92). As Diller suspected and as Taliaferro asserted (p. 90), these sediments "are preserved in the deepest part of the trough of a tightly compressed overturned syncline". Thus they are limited in areal distribution to a narrow belt north and east of Oroville. Outcrops extend from a short distance south of the Feather River northward to an arm of North Table Mountain, where the beds disappear beneath flat-lying Tertiary strata. The east flank of the syncline is in contact with the Oregon City volcanics along a fault. South of the Feather River, the syncline is obliquely truncated by the same fault, and outcrops of the Monte de Oro were not observed south of that point.

On the west side of the Feather River, about one mile upstream from Oroville, the writer observed a thin stratum of pebble-conglomerate and sandstone much like that of the Monte de Oro at the type locality. This is probably the same as the belt noted by Diller (1908a, p. 390) lying "one-fourth mile west of the mouth of Morris Ravine", and "interbedded with the regular tuffs". These beds dip steeply toward the east; graded-bedding and small-scale cross-bedding indicate that they are not overturned. They thus lie on the west flank of a syncline whose axis is about one mile west of the main belt of Monte de Oro outcrops. These sediments appear to be interbedded with the Oregon City volcanic rocks and may represent a slightly higher horizon in the Monte de Oro than the base of the formation at its type section. At the northeast corner of Thompson flat, a small, isolated exposure of black, massive, carbonaceous sandstone crops out from beneath Quaternary stream gravels. It is probably referable to the Monte de Oro, although the lack of exposures makes a valid structural interpretation seem impractical in this part of the area.

Slightly sheared argillaceous sandstone and siltstone constitute a major part of the Monte de Oro sediments. Conglomerate, though the most conspicuous lithologic element, is subordinate. Clay slate is widespread in the formation, but is far less abundant than siltstone and sandstone.

The sandstone is dominantly fine- to medium-grained, but all variations from very fine- to very coarse-grained sandstone are known. It commonly grades, on the one hand, into siltstone or, on the other, into granule conglomerate. That in the lower part of the section is greenish-gray and is considered to be volcanic sandstone. It appears to be identical to the volcanic sandstone of the underlying Oregon City Formation. The bulk of the material in the lowest part of the Monte de Oro is believed to have been reworked from the Oregon City volcanics, although some tuffaceous admixture may have been derived directly from waning volcanic outbursts. The volcanic sandstone passes gradually upward into non-volcanic sandstone. It possesses none of the green coloration of the underlying beds, but is various shades of gray or buff. It contains a notable percentage of black, carbonaceous, argillaceous matrix material. Among the grains, rather fresh feldspar is abundant, along with a noteworthy amount of detrital chert and quartz. Fragments of slate, chlorite schist, and dense volcanic rocks are present in lesser quantities.

The associated siltstone is typically black or dark gray on fresh exposure, but weathers to light gray or pale greenish-buff. It contains a considerable admixture of black clayey material and is usually somewhat slaty. The siltstone is frequently rather sandy and micaceous. Black clay-slate is subordinate to the finer-grained clastics. It often weathers to the same colors as those seen in the siltstone. The cleavage usually exhibits little luster, and is irregular and imperfectly developed. In most cases, secondary mica is not discernable with the hand lens. The cleavage surfaces are commonly cluttered with fragmentary but otherwise undisturbed plant remains. The plants are marked by a lustrous black residue arranged according to the original organic structures. The thin perfectly planar "roofing-slate" type of cleavage was nowhere observed in the slate.

The sandstone, siltstone, and slate of the Monte de Oro are, as a rule, thin-bedded. Thin alternations of argillaceous and arenaceous strata are common. Small-scale cross-bedding and, in some places, graded bedding occur in the sandstone. As in the case of the slate, the bedding surfaces in the thin-bedded siltstone and sandstone are frequently littered with well-preserved plant fossils.

Conglomerate is conspicuous at many horizons in the Monte de Oro. It includes thin pebble or granule stringers in the sandstone (Fig. 18), as well as lenticular, more or less massive pebble-cobble conglomerate beds approaching 40 feet in thickness. Much of the conglomerate consists solely of granules and pebbles, while some, especially in the thicker beds, is ill-sorted, containing both pebbles and cobbles in abundance

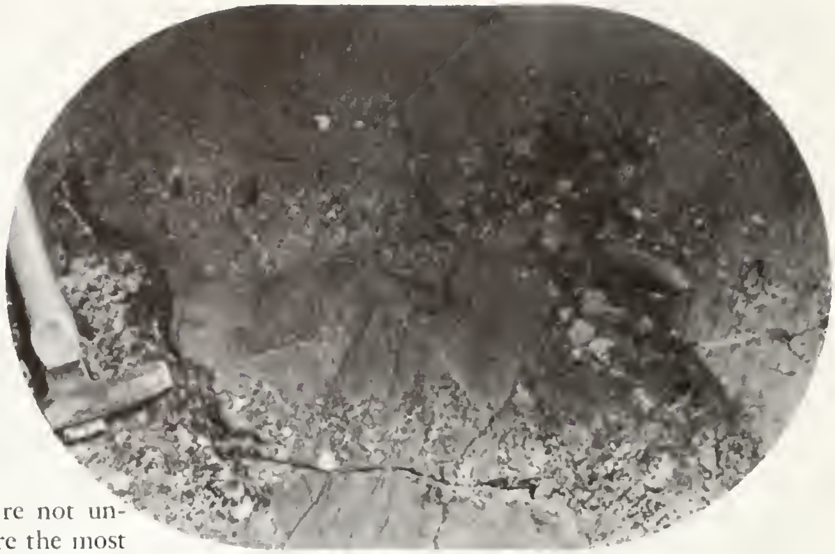


Figure 18. Granule-pebble beds in sandstone. Monte de Oro Formation. North bank of Feather River.

(Fig. 19). Cobbles up to 8 inches across are not uncommon, though pebbles of 2 or 3 inches are the most abundant. The pebbles and cobbles are well-rounded to subangular, and are set in a matrix of ill-sorted, argillaceous sandstone. The conglomerate is poorly sorted with respect to the composition of component pebbles and cobbles. Certain rock types are invariably present, although their relative proportions are highly variable. Both sedimentary and volcanic rock types occur together, but in most cases the latter appear to be the more abundant of the two. Among the prominent constituents are grayish-green plagioclase-quartz porphyry (dacite?), light gray to black chert and black slate. Less abundant types are fine-grained basic igneous rocks, of intrusive aspect, and dark-colored, dense, indeterminate volcanic rocks. It is signficant that the volcanic rocks which most commonly occur as pebbles and cobbles in much of the Monte de Oro conglomerate are not of the same types which characterize the underlying Oregon City Formation. It is probable, then, that the volcanic pebbles, as well as the accompanying chert and slate, were not indigenous to the basin of deposition but were derived from an older terrane which may have included elements of the Calaveras Formation. Bedding in the conglomerate is usually ill-defined, and, where observed, is made manifest by thin partings of sandstone or by the concentration of sub-equally sized pebbles parallel to the bedding. The conglomerate often fills channels in the underlying beds.

The Monte de Oro sediments generally are very well indurated. They apparently owe their consolidation not to the presence of an introduced cementing agent but to the effects of compaction upon their matrix materials. They have obviously been subjected to some directed stresses, but cleavage, where observed, is generally vague and incompletely developed. However, the sediments adjacent to the postulated reverse fault which cuts the east flank of the syncline are intensely sheared. Here, cleavage is well-developed in the finer-grained sediments, while finer-grained conglomerate involved in the shearing shows granules and

Figure 19. Pebble-cobble conglomerate. Monte de Oro Formation. North bank of Feather River.

small pebbles having a markedly "strung-out" appearance.

As seen in thin section, the typical sandstone of the Monte de Oro contains from 20 to 25 percent of argillaceous matrix material. Most of the latter is indeterminate except for small quantities of "sericite". The grains are dominantly angular to subangular, and are poorly sorted both as to size and to composition. The grains consist of quartz (10-15%),* detrital chert (20%), feldspar (albite to andesine; 30-40%), and lithic fragments other than chert (dense volcanic rocks, slate; 25-30%). The specimens examined thus are classified essentially as arkosic graywacke or as intermediate cases between lithic and arkosic graywacke. The more coarse-grained types show some increase in grain-roundness, and tend to have a much higher proportion of lithic material and correspondingly less quartz and feldspar. A semischist, once a granule-fine pebble conglomerate, was collected from the faulted eastern margin of the Monte de Oro outcrops along the Feather River. Under the microscope, nearly all of the clasts appear to have been more or less crushed and drawn out into lenticular bodies. These are separated by thin, closely-spaced undulate laminae of microcrystalline, partly opaque material which traverse the rock with subparallel orientation. The chief constituent of the microcrystalline material is white mica. This rock presents a sharp contrast to its adjacent, practically undeformed counterparts.

North of the Banner Mine, on the east side of the Monte de Oro belt, a narrow vein-like body of dense, carbonate-rich rock crops out for over 1000 feet along the Monte de Oro-Oregon City contact. Under the microscope, the rock is seen to be a veined, xenoblastic aggregate of calcite (50%), sericite (20%), quartz (10%), albite (10%) and chlorite (5%), with minor amounts of sphene and "limonite". The rock is thought to have formed by hydrothermal processes related to the fault along which it lies.

The maximum exposed thickness of the Monte de Oro Formation is approximately 1300 feet. It is underlain conformably by the Oregon City Formation. As was pointed out above, the contact is transitional. The Monte de Oro is the youngest of the bedrock units mapped in the Oroville quadrangle, and is therefore overlain with marked angular unconformity by the various formations of the "superjacent series". The oldest strata known to rest directly on the Monte de Oro are those of the "auriferous gravels" (Eocene).

Reference has already been made to the fossil flora which is preserved in the Monte de Oro sediments. The plants were first noted in the literature by Turner (1896, pp. 548-549), who quoted a letter from Professor W. M. Fontaine. Fontaine summarized his conclusions as follows:

> Taking all the evidence, I think it can be positively said that *this flora is not older than the uppermost Triassic, and not younger than the Oolite.* I feel pretty sure that it is true Rhetic, somewhat younger than the Los Bronces flora of Newberry, and the Virginia Mesozoic coal strata. It is much like the Rhetic flora of France, made known by Saporta. . . . *I do not think the fossils now in hand suffice to fix narrowly the age, which may be lower Jurassic.*

Fontaine (1900, pp. 342-368) described and figured 28 species from the "Oroville beds" (Turner's Monte de Oro Formation). Of these, 7 are identical with forms "found by Heer in the Jurassic formation which he regarded as middle Brown Jura", approximately the equivalent of the lower Oolite of Scarborough. Fontaine stated (p. 367):

> The comparison of the Oroville plants with known floras shows that most of the forms for which any relationship with known plants can be made out find their like in the Lias and Oolite, or without distinguishing these, in the Jurassic. As the Oolitic forms are predominant, we may conclude that the age of the flora is not only Jurassic but rather late Jurassic, probably about the age of lower Oolite.

Fontaine later (1905, pp. 142-143), in connection with the description of a well-preserved Jurassic flora from Douglas County, Oregon, noted that 12 of the 77 species identified there are found also in the Monte de Oro flora. 14 of the Oregon species are found in the lower Oolite of Yorkshire, and several of them are "highly characteristic of the lower Oolite". Fontaine (p. 144) noted that "the key to the whole matter is the correctness of the determination of the age of the Yorkshire (lower Oolite) beds". According to Imlay (1952, Pl. 2), the Inferior oolite is Bajocian (lower Middle Jurassic).

In addition to the flora, the Monte de Oro Formation contains a rather poorly preserved invertebrate fauna, which has furnished far less information as to the age of these strata than has the flora. The fauna was first described by Stanton (quoted by Diller, 1908, p. 390). Stanton's statement on the first collection is as follows:

> Unfortunately the collection does not contain anything specifically identifiable with fossils from any well-known horizon on the west coast. The most abundant form is an aviduloid shell that I doubtfully referred to *Eumicrotis.* With these are specimens of *Pinna, Trigonia,* and *Belemnites.* The whole assemblage has a decided Jurassic aspect, and, in my opinion, the formation yielding them is older than the aucella-bearing Mariposa formation.

Another collection was subsequently made, concerning which Stanton (Diller, 1908, p. 390) noted:

> Perhaps the most important addition [to the previous collection] is the form doubtfully referred to Aucella. It is represented by one fairly good valve and a fragment of another, which might belong to either *A. piochi* of the Knoxville or to *A. erringtoni* of the Mariposa, as far as can be determined from the features preserved. Unfortunately, there is no right valve in the collection and the generic reference is not positive. If it is really an *Aucella,* the age of the beds is either Mariposa or Knoxville—more probably the former. The general character of the forms is suggestive of the older Jurassic faunas of the Taylors-

* Percent of grains.

ville region, but it must be admitted that there is no definite evidence of this.

Stanton's list of "all shells yet discovered in the plant beds at Oroville" included *Ostrea* sp., *Pecten* 2 or 3 sp., *Aucella* (?) sp., *Modiola* sp., *Trigonia* sp., *Cardium* (?) sp. (rather than *Eumicrotis* of the previous report), and *Belemnites* sp. Allen collected several invertebrate fossils in beds apparently belonging to the Monte de Oro Formation near Thompson Flat, north of Oroville. Regarding these, Stanton (quoted by Allen, 1929, pp. 370-373) stated:

> The collection includes at least three species of pelecypods of which two belong to *Trigonia* and the third and most abundant form is a pteroid shell which I have had in two previous collections from the Monte de Oro formation and referred first to *Eumicrotis* ? sp. and afterwards to *Cardium* ? sp. On reexamination of the old material in connection with your somewhat better specimens I will return to my first determination and call the form Eumicrotis ?, since it seems to belong to Pteriidae, a family formerly called Avidulidae. This form is the most abundant invertebrate in the collections from the Monte de Oro formation as well as in your collection, and I consider it sufficient evidence that your new locality, which as you state is about three miles from the type locality of the Monte de Oro formation is also in that formation.
>
> Each of the two species of *Trigonia* is represented by an excellent imprint, casts from which give a very good idea of the form and sculpture. The smaller specimen belongs to the group Clavellatae and is distantly related to *Trigonia dawsoni* Whiteaves. This I consider a distinctly Jurassic type.
>
> The larger imprint apparently belongs near the Alifornis subgroup of the Scabrae, which is chiefly a Cretaceous group, but your species departs considerably from the usual form of the group and is certainly distinct from anything that has been described from the Pacific coast. The species is also represented by an internal cast of a small specimen.
>
> Taking into consideration all the invertebrate collections I have seen from the Monte de Oro formation together with the testimony of the plants, I think that the formation is of Jurassic age—most probably Upper Jurassic. Whether it is equivalent to part of the Mariposa formation I do not know, but the abundance and excellent preservation of fossils at this new locality makes me hopeful that a sufficient fauna will yet be found to enable us to classify it accurately.

The Mariposa Formation has been shown to be early Upper Jurassic (Taliaferro, 1942, pp. 77-81).* Thus a correlation of the Monte de Oro, if the evidence of the plants is correct, with the Mariposa seems invalid.

* Recently acquired fossil evidence suggests that the Oregon City Formation is, at least in part, of Late Jurassic (Oxfordian) age. It follows that the Monte de Oro Formation, lying stratigraphically above the Oregon City, may actually be Upper Jurassic and is possibly correlative with the Mariposa Formation (mid-Upper Jurassic, i.e. late Oxfordian to early Kimmeridgian), a well-known unit in the Sierran foothills area farther south. Certain similarities of lithology between the two formations exist, although the Monte de Oro is generally coarser grained than the typical Mariposa. That such a correlation may be valid was first suggested by Stanton (Diller, 1908, p. 390) and later by Imlay (1961, p. D-9) on the basis of the invertebrate fauna.

Taliaferro (1942, pp. 90-91), regarding the Monte de Oro, stated:

> These beds, traceable for only a short distance away from the Feather River, form an isolated area more than 40 miles from any belt of Sierran Jurassic sediments. Their isolated position is not due to non-deposition of the Jurassic over the Sierran region to the east but to removal by erosion following the Nevadan revolution; the Monte de Oro beds were preserved because of their structural position.

Taliaferro further believed (p. 92) that the Monte de Oro represents deposits formed near the western edge of the Middle Jurassic sea:

> The state of preservation of the plant remains in the Monte de Oro and the character of the sediments indicate deposition very close to the western margin of the Middle Jurassic sea which extended eastward. The sediments are strongly cross-bedded and channeled and were evidently deposited in very shallow water. The sandstones are arkosic and contain an abundance of rather fresh angular feldspar and quartz grains. The appearance of the plants and the lack of maceration shows that they were not transported for any distance and must have been entombed very close to the forests from which they were derived.
>
> The Monte de Oro beds are especially important in indicating a point on the position of the western shore line of the Middle Jurassic sea. Unfortunately, these sediments have not been preserved over wide areas.

The present writer is in agreement with Taliaferro's statement regarding the probable nearshore character of the Monte de Oro beds. The ill-sorted nature of the sediments suggests that deposition was comparatively rapid, while the composition of much of the clastic material indicates that the detritus was eroded and transported from a landmass in which the terrane contained, in part, rocks similar or identical to those of the Calaveras.

### Intrusive Igneous Rocks

Calc-alkaline, ultrabasic, and alkaline igneous rocks have been intruded into the bedrock terrane. Some occur as dikes or small pluglike bodies, others appear to have been intruded in the form of sills, while one of the largest may have been emplaced as a volcanic conduit. Certain of these intrusives must have been injected prior to, or in the early stages of, the latest folding and regional metamorphism, which attended the orogenic phase of the Nevadan revolution. Others apparently post-date the metamorphism and may actually represent minor forerunners of the batholithic emplacement which followed the Nevadan orogeny throughout the Sierra Nevada. With but one or two possible exceptions, representatives of the Nevadan granodiorites and allied types have not been found within the Oroville quadrangle, although such rocks occur on a batholithic scale a few miles to the east and to the north (Turner, 1898; Hietanen, 1951; Compton, 1955).

One difficulty connected with the dating of the various intrusions is that the great majority of them are isolated, in regard to areal extent, within the Calaveras Formation and do not contact younger bedrock units, such as the Oregon City and Monte de Oro Formations. Furthermore, it is probable that all of the intrusive masses of a particular rock type, such as serpentine, do not mutually correspond in age and may well be separated by time gaps on the order of several geologic periods. Thus, the order in which the various intrusive types are taken up herein is to be considered at best only an approach to the sequence of intrusion as it actually occurred.

### Metagabbro and Serpentine

Basic and ultrabasic intrusive rocks, now largely represented by metagabbro and serpentine, respectively, have invaded the Calaveras strata in the northeastern part of the area. Many of these instrusives occur in relatively long narrow sheets or lenses which exhibit a broad concordance with the bedding and schistosity of the enclosing strata, suggesting that they were intruded in the form of sills. With one possible exception, the bodies of metagabbro are adjacent to serpentine, so that the two together often form composite intrusive masses. In some cases, serpentine appears to have been injected later than the metagabbro, but because of the close spatial relationship which exists between the two, it is probable that they are closely related in time as well, perhaps as differentiates of the same magma.

*Metagabbro.* Several small intrusive masses, composed largely of metamorphosed basic igneous rock, occur in the older bedrock terrane. These are believed to have once been gabbro, and accordingly are shown on the geologic map under the term *metagabbro*. Three types, differentiated according to the mineral assemblages now present, are recognized.

The rocks of the first type, examined in hand specimen, have the appearance of somewhat altered hornblende diorite or gabbro. Such rocks were mapped on the south and west sides of Jordan Hill, in the canyon of Concow Creek, and in the vicinity of Concow school. The outcrop areas are irregular in plan, but tend to show some elongation roughly parallel to the structural grain of the country rock. It is likely that rocks of this type seen on Concow Creek are continuous with those on Jordan Hill, but the relations are obscured by a cover of nearly flat-lying Tertiary strata.

In the field, this type is medium-gray to dark greenish-gray and is massive to slightly schistose or sheared. Average grain-size lies between medium and fine, although coarse-grained variants occur at several localities. Frequently, the variation in grain-size may be quite rapid; transitions from fine-grained to coarse-grained rock may occur even within a single hand specimen. Most of the rock is more or less equigranular, although a porphyritic type occurs sparingly. Minerals determinable with the hand lens include abundant dark green or black amphibole and "saussuritized" plagioclase, veinlets of microcrystalline epidote minerals, and, in some cases, a few small cubes of pyrite.

Under the microscope, these rocks are seen to be composed principally of plagioclase, actinolite, and minerals of the epidote group. The texture varies from allotriomorphic-granular to hypidiomorphic-granular, with the former predominant over the latter. In some specimens of the hypidiomorphic-granular type, slightly elongate, more or less rectangular laths of feldspar, which in general aspect may appear to be euhedral or subhedral, show in detail very few euhedral boundaries. Slightly clouded sodic plagioclase ($An_0 - An_{12}$) constitutes from 50 to 60 percent of the rock. In a few rocks, crystals of original feldspar have been thoroughly replaced by a microcrystalline "saussuritic" aggregate of clinozoisite, "sericite", albite, quartz, epidote, chlorite, calcite, and sphene. The common mafic mineral of these rocks is pale green actinolite, which makes up from 25 to 35 percent of the whole. It generally occurs as slightly elongated or nearly equant, roughly prismatic, anhedral crystals, the ends of which commonly appear to "fray-out" into adjacent feldspars. A uralitic origin of part, if not all, of the amphibole is demonstrated by the occasional occurrence of amphiboles having pyroxene habit and the infrequent preservation of sieve-like relicts of augite in the cores of such amphibole crystals. In a slightly porphyritic type from near Concow School, anhedral masses of actinolite are partly interstitial to randomly oriented plagioclase laths, suggesting that the original pyroxene of a diabasic texture has been replaced by the amphibole. The epidote minerals are present in every section examined, either as clinozisite, or, less often, as epidote. They constitute from 5 to 15 percent of the rock, and may occur as veinlets, "clots" of randomly oriented, idioblastic prisms, or as individual subhedra disseminated through the rock. In a few cases, clinozoisite appears to have definitely replaced feldspar. Sphene is generally present in amounts ranging from a few to 10 percent, and is always in the form of irregular, cryptocrystalline clusters. Other minerals occurring in markedly subordinate amounts are calcite, chlorite, "sericite", quartz, and pumpellyite (?). Evidence of minor post-crystallization deformation is abundant. Under the microscope, most specimens show one or more narrow zones along which brecciation and displacement of the components have occurred. Many of the feldspar and amphibole crystals have been fractured and slightly bent.

The abundant development of clinozoisite and epidote in these rocks and the occurrence in some of them of "saussuritized" plagioclase suggest that a variety of plagioclase considerably more calcic than that now present once dominated the mineral assemblage. Similarly, it is considered likely that a large part, if not all, of the actinolite has formed at the expense of original pyroxenes. From these assumptions regarding the mineralogy and from a consideration of the tex-

Figure 20. Banded metagabbro in contact with green serpentine. Part of contact marked by greenish-black, tough aphanitic serpentine. West branch of Feather River near Cape Horn..

tural features already described, it is concluded that these rocks are the derivatives of normal gabbro and diabase. It is likely that they have formed in response to the same low-grade regional metamorphism which has affected the metasedimentary and metavolcanic rocks of the adjacent terrane. They more or less correspond to certain of the rocks described as "epidiorites" in the British Isles. Wiseman (1934) has exhaustively treated the progressive metamorphism of epidiorite sills in the Scottish Highlands. The rocks described herein appear to be similar to the low-grade epidiorites described by Wiseman (pp. 357-378) as having been formed in the chlorite and biotite zones of regional metamorphism, although the average anorthite content of the plagioclase in the Oroville rocks may be slightly higher than in the Scottish examples.

The second type of metagabbro might best be termed a "saussurite gabbro". It is well-exposed on the south end of Jordan Hill and along adjacent parts of Concow Creek and the West Branch. It is also the dominant type in the metagabbro body which underlies part of Gold Flat and the ridge to the southeast. This is typically a dark to somewhat light greenish-gray, medium- to coarse-grained, equigranular rock. The only minerals readily identified in hand specimens are pyroxene and plagioclase. The usual ratio of feldspar to pyroxene is roughly 3:2, although in some specimens, feldspar is somewhat subordinate. The plagioclase invariably is light green or gray, with a dull, somewhat "greasy" appearance on cleavage planes. In most specimens of the medium-grained rock, both twinning and cleavage are largely or wholly obliterated. On the other hand, the pyroxene, which is dark greenish gray and often exhibits the prominent parting of a diallage variety, usually appears rather fresh. At a few localities, crystals of pyroxene up to 1 inch in length occur.

In thin section, the "saussurite gabbro" is seen to consist largely of embayed and slightly uralitized diopsidic augite and more or less thoroughly altered plagioclase. The plagioclase has been replaced by a dusty, cryptocrystalline aggregate of secondary minerals, among which clinozoisite and "sericite" can be definitely recognized and albite, carbonate, and sphene are tentatively identified. A few small, ragged relicts of an original calcic plagioclase may be present, but were not identified with certainty. Some relict cleavage is still obvious in the altered feldspar. Occasional patches of microcrystalline chlorite appear to have replaced some ferromagnesian mineral, such as olivine. In one thin section examined, minute prisms of secondary apatite are abundantly disseminated throughout the rock.

The third type of metagabbro distinguished in the area most likely represents a modification of the "saussurite gabbro" described above. Wherever observed, it has a close spatial association with serpentine. It occurs, in subordinate quantity, along with the "saussurite gabbro" in the vicinity of Gold Flat. It is also found as masses, measuring from a few tens of feet to 900 feet in length, completely isolated within the serpentine at Nelson Bar and in the serpentine that lies less than a mile southwest of Serpentine Point. The rock is of much lighter color than the metagabbros previously described. It consists dominantly of pale gray to white, microcrystalline material in which are distributed subrounded or irregular lumps, measuring up to 5 or 6 mm across, of a pale yellow-green to dark green, translucent, waxy substance. The overall appearance of the rock suggests that the original texture, one of medium to coarse grain-size, is reflected in the arrangement of the two different materials, but that all semblance of original crystal faces has been obliterated. In some places, this rock has a well-defined, steeply dipping stratified aspect which is manifested by the slight concentration of the green lumps in parallel layers. This structure is suggestive of the layering seen in some gabbros (Fig. 20).

Petrographic examination of the rock reveals that the waxy green material is a microcrystalline aggregate of a flaky chloritic (?) mineral or possibly some type of serpentine. The dominant white material seen in the hand specimen appears largely as a dusty cryptocrystalline mass in which clinozoisite is an important constituent. The other minerals present are indeterminate. It is thought that the green chloritic (?) masses have formed at the expense of original pyroxene and other ferromagnesian minerals, while the "saussuritic" clinizoisite-rich aggregates have been formed from calcic plagioclase.

The occurrence of both this type of metagabbro and the "saussurite gabbro" together in the body at Gold Flat suggests that both are derivatives of the same original gabbroic rock. The close spatial relationship between the more altered metagabbro and the serpentine suggests that the destruction of the ferromagnesian minerals which were present in the original gabbro and which are still present, in part, in the "saussurite gabbro" is the result of the same processes of alteration by which the ultramafic intrusions were serpentinized.

*Serpentine and allied rocks.* Serpentine and rocks closely allied to it are of widespread occurrence in the northeastern part of the quadrangle. Petrographic evidence indicates that some was originally peridotite, but some is so completely serpentinized that its original nature cannot be determined with certainty. It occurs either as relatively long, narrow belts, more or less concordant with the adjacent strata, or as irregular masses which cut sharply across the regional structure. Some of the more concordant bodies are thought to represent sills which were intruded prior to the folding of the enclosing rocks. The best example of such a relationship is the thin sheet of serpentine which trends northwestward for more than three miles from a point one-half mile west of Yankee Hill. Metagabbro is associated with the serpentine in the northwest part of this belt. It is distinctly possible, however, that some of the sheet-like, more or less concordant bodies of strongly sheared serpentine were injected as "cold intrusions" along unrecognized fault zones. A markedly discordant mass of serpentine is that which crops out on the west side of the West Branch between Nelson Bar and Cape Horn.

The serpentine varies considerably in its appearance. Some is wholly aphanatic, some may be finely crystalline, and some carries numerous large bastite pseudomorphs. Most of the more massive varieties are nearly black with a slight greenish cast. Others are pale green or greenish-white streaked with black. These frequently exhibit highly irregular cleavage and abundant slickensides, the results of shearing. Lenticular knots of more resistant, massive serpentine within belts of the strongly sheared variety are common. Subordinate quantities of talc schist or, in a few places, talc-tremolite schist are associated with much of the serpentine, and these commonly occur at the margins of a serpentine mass. A noteworthy example of such an occurrence is seen at many places on both flanks of a serpentine belt which crosses Deadwood Creek at the junction of Ponderosa Way and Oro-Concow Road. Of common occurrence are sheets of talc schist, seldom greater than a few feet in thickness, which are intercalated with the Calaveras slates and metavolcanic rocks. Their schistosity is invariably parallel to that of the country rock. Many of them are not spatially associated with serpentine and it is likely that they represent original serpentine in sheets so thin that metamorphism to talc schist has gone essentially to completion.

A serpentine belt lying just north of, and adjacent to, the northernmost outcrops mapped as the Hodapp Member is bordered on the south by a thin sheet of partly altered, fine-grained diabase. The diabase, which can be traced for about a mile, is thought to represent a marginal facies differentiated from the ultrabasic mass at the time of injection. The close spatial, and possibly genetic, relations between some of the basic intrusive rocks and the serpentine has been previously discussed.

As seen in thin section, the more massive serpentine consists in large part of fine-grained, flaky antigorite. The plates may be randomly oriented, or may show a well-defined preferred orientation in one or sometimes three directions. In the latter case, the three orientation-directions are nearly at right angles to one another, forming a reticulate, boxwork-like aggregate. "Mesh-structure" is shown where discontinuous, curving trains of magnetite (?) dust presumably mark the outlines of former olivine crystals. Anhedral "crystals" of "bastite" serpentine, up to 5 mm across, often lend a porphyritic appearance to the rock. These are presumed to have formed as pseudomorphs after an original orthopyroxene. Closely spaced, subparallel veinlets of chrysotile transact the whole. Dolomite, in spherical masses of radiating crystals, is locally abundant. A common accessory in the serpentine is chromite, which occurs in highly irregular grains. In some of the serpentine, it is of sufficient concentration to have excited some mining activity. A few occurrences of altered ultrabasic rocks still containing a part of the original minerals are known in the area. One of these, associated with the serpentine belt in the north part of Pington Ravine, is a very coarse-grained, allotriomorphic granular rock consisting largely of tremolite (60%) and diopside (35%), with some enstatite and chlorite.

The age of most of the serpentine bodies and composite serpentine metagabbro bodies in the area cannot be determined closely. Nor is it clear that together they represent a single period of intrusion, and there is some evidence that they do not. Since all of the serpentine studied by the writer bears the mark of low-grade dynamothermal metamorphism, it follows that all were emplaced prior to, or in the early stages of, the latest deformation which has caused this metamorphism—the Nevadan orogeny. Several of the more or less concordant, sheet-like masses are believed to have been injected into the Calaveras rocks as sills, and may well have been involved in the earliest folding which affected the Calaveras. On the other hand, certain of the serpentine bodies, notably those near Nelson Bar and Cape Horn, are clearly discordant, and may have been intruded after the Calaveras strata and earlier (?) serpentine was initially folded. Only one small body of serpentine was found to crop out in the area underlain by the Oregon City Formation (? middle Jurassic), and it must be of later age than any serpentine intruded prior to the earliest folding of the Calaveras, if such folding actually occurred before the deposition of the Oregon City rocks.

Two periods or phases of intrusion of ultrabasic rocks in the region immediately east of the present area were shown to exist by Hietanen (1951, pp. 578, 580), who found dikes of serpentine and allied rock-types transecting earlier serpentine. Compton (1955, Pl. 1) considered a metaserpentine mass occurring in the Bidwell Bar area, east of Oroville, to be possibly as old as late Paleozoic. Knopf (1929, p. 20), after studying the rocks of the Mother Lode region, concluded:

> Although it is commonly assumed that the serpentine is all of the same age, it is also possible that some of the serpentine—that wholly inclosed in Calaveras rocks—is older than that which is intrusive into the Mariposa slate [Jurassic].

Taliaferro (1942, pp. 94-95) believed that the great majority of ultrabasic intrusive rocks in the Sierra Nevada "were intruded prior to the Nevadan folding of the Jurassic sediments and volcanics since they are folded with them" and that "these ultrabasic intrusives were emplaced in a later stage of geosynclinal sinking after the accumulation of a thick prism of sediments". The frequent association of ultrabasic intrusions with geosynclinal sediments and volcanics and the fact that emplacement of such intrusions normally occurs prior to, or soon following, the initiation of folding which marks the collapse of the geosyncline have been noted by several workers. (cf. Benson, 1926; Taliaferro, 1942, p. 95; 1943a, p. 153; Turner and Verhoogen, 1951, pp. 201-202, 239-242). The serpentine and related intrusives which occur in the area of study no doubt represent such an association with geosynclinal strata and orogenic movements. With but few exceptions, however, it cannot be clearly established whether individual intrusions are genetically related to post-Calaveras, pre-Jurassic (?) movements or to the Jurassic Nevadan orogeny.

#### Monzonite

A small body of augite monzonite crops out at Yankee Hill. The mass, which has intruded slates and metavolcanic rocks of the Calaveras Formation, is quite irregular in plan. A slender apophysis projects for about one-half mile south and east from the main body. The rock is typically massive, but locally shows closely spaced joints. Fresh surfaces are dark greenish-gray, while weathered surfaces are mottled orange and pale yellow. The monzonite is equigranular and varies from fine- to medium-grained. Minerals visible in the hand specimen include abundant plagioclase and orthoclase, lesser amounts of augite, and widely disseminated pyrite.

Petrographic examination shows the monzonite to be composed principally of euhedral to subhedral plagioclase (andesine) and anhedral orthoclase. The two together compose 60 or 70 percent of the rock, with orthoclase slightly subordinate to plagioclase. Frequently the orthoclase partly or wholly encloses euhedral laths of plagioclase. The orthoclase is reasonably fresh, as is some of the plagioclase, but most of the plagioclase has been considerably altered to a saussuritic complex of microcrystalline clinozoisite, chlorite, epidote, and albite. Slightly uralitized diopsidic augite, in equidimensional, anhedral grains, composes about 20 to 25 percent of the rock. Scattered grains of sphene, magnetite, and pyrite are minor accessories. Because of its somewhat metamorphosed condition, the monzonite is thought to represent a pre-Nevadan intrusion, since, so far as the writer is aware, the intrusive rocks associated with the Nevadan revolution, except for the basic calc-alkaline and ultrabasic types, are unmetamorphosed.

#### Hornblende-Quortz Diorite

Altered hornblende-quartz diorite forms a small outcrop at the east edge of the quadrangle. It is apparently intrusive into the Calaveras rocks and represents only the westernmost extremity of a somewhat larger mass which lies just east of the area. The rock is greenish-gray, massive, medium- to coarse-grained, and allotriomorphic-granular. It contains 35 to 40 percent of dark green or black amphibole, 15 percent of quartz, and 45-50 percent of feldspar.

Under the microscope the amphibole proves to be of two different types. One is very pale somewhat fibrous green actinolite, clearly of uralitic origin, for a few "motheaten" crystals of diopsidic augite have survived the alteration. The second amphibole is equally abundant, and is a light greenish-brown hornblende. It occurs as non-fibrous, anhedral crystals, a few of which partly enwrap the relict augite as reaction rims. The dominant feldspar (making up 30-40% of the rocks) is a rather acid plagioclase, in some cases perhaps as sodic as albite. It occurs as very irregular, anhedral, partly altered crystals. Parts of the rock are large, microcrystalline, xenoblastic aggregates consisting almost wholly of "sericite" with a subordinate quantity of clinozoisite. It is likely that these aggregates are compounded of the alteration products of an originally more calcic plagioclase and perhaps of orthoclase as well. Anhedral pools of clear quartz constitute about 15 percent of the rock. Clinozoisite (5-10%), epidote, and sphene occur as scattered large grains. Veinlets, composed principally of clinozoisite and secondary quartz, transect the rock at several points. As in the case of the monzonite described above, this rock, because of its altered condition, is thought to antedate the intrusion of the Nevadan batholiths.

#### Bosolt Porphyry

A dark-colored, somewhat altered, markedly porphyritic basalt which underlines the entire summit of Glover Ridge is thought to have been emplaced as a plug-like, shallow intrusive mass. In plan, the mass has the form of a crude rectangle with rounded corners, and covers an area approximately one and one-fourth miles in length and from one-half to three-fourths of a mile across.

As observed in the field, the basalt is generally quite tough and massive, except for a slight degree of shearing. It displays no semblance of layering or other features which might seem to require an extrusive, rather than intrusive, origin, except for a few locally brecciated parts. It is dark greenish-gray on fresh exposure, and the texture is dominantly porphyritic with a microcrystalline groundmass. More or less evenly distributed euhedral to subhedral phenocrysts of augite are abundant in most outcrops. These frequently measure over 5 mm across, and some as large as 10 mm in maximum dimension occur. Lath-shaped phenocrysts of "saussuritized" plagioclase, still showing polysynthetic twinning in some cases, are found at relatively few localities. At one or two points, scattered small amygdules are seen, perhaps indicating that the rock was emplaced at a relatively shallow depth. Of local importance in some parts of the mass is a distinctly brecciated appearance. Angular to subangular fragments, ranging from a fraction of an inch up to 2 feet across, are held in a matrix nearly identical to the rock composing the fragments themselves. The brecciation is made obvious by a very slight difference in color between the two components. Such occurrences are interpreted as being due to autobrecciation in moving magma rather than to any post-magmatic tectonic activity.

A typical specimen of this rock, selected for analysis (No. 1), was examined under the microscope. It is porphyritic and in part glomero-porphyritic, with phenocrysts composing about 80 percent of the whole. Randomly oriented euhedral to subhedral laths of altered plagioclase (60%), usually less than 1 mm in length, and euhedral to subhedral, more or less equidimensional phenocrysts of slightly titaniferous diopsidic augite (20%), measuring up to 5 mm across, are held in a microcrystalline, allotriomorphic-granular groundmass. The latter is composed principally of albite, chlorite, clinozoisite, epidote, and possibly quartz. Small crystals of augite are disseminated throughout the groundmass. Part of the chlorite is concentrated in small masses, the outlines of which are sometimes regular and are highly suggestive of the replacement of some pre-existing mineral, such as olivine. Small ragged cryptocrystalline aggregates of sphene are common. A few narrow veinlets of calcite and sericite or of clinozoisite and calcite transect the rock. The plagioclase has been thoroughly altered to microcrystalline aggregates consisting chiefly of "sericite", albite (?), and possibly quartz, and minor amounts of epidote and chlorite. The original crystal-outline of the feldspar has been preserved, as has the cleavage. In a few crystals polysynthetic twinning and zoning are still recognizable. The augite, on the other hand, is markedly fresh, except for a slight development of chlorite along cracks.

The molecular ratios between certain of the oxides are $MgO: CaO = 0.90$, $CaO: Na_2O = 3.06$, and $Na_2O: K_2O = 3.61$. The silica content of the rock indicates that it is of basaltic composition. As was previously proposed, the close correspondence of certain parts of the analysis, normative composition, and oxide ratios of this with those of a specimen from the Oregon City formation may well indicate that the two are correlative.

*Chemical analysis of Specimen No. 1*
*(W. H. Herdsman, analyst)*

| Chemical Analysis No. 1 | | Calculation of Norms | |
|---|---|---|---|
| $SiO_2$ | 46.08 | Q | none |
| $Al_2O_3$ | 16.84 | or | 8.80 |
| FeO | 8.06 | ab | 23.76 |
| $Fe_2O_3$ | 2.68 | an | 27.84 |
| $TiO_2$ | .92 | ne | 3.59 |
| MnO | .14 | di | 12.49 |
| CaO | 9.33 | hy | none |
| MgO | 6.02 | ol | 15.64 |
| $K_2O$ | 1.42 | ap | 1.04 |
| $Na_2O$ | 3.38 | il | 1.76 |
| $H_2O$ ( −105°C) | .42 | mt | 4.05 |
| $H_2O$ ( +105°C) | 3.56 | | |
| $CO_2$ | .45 | | |
| $P_2O_5$ | .39 | | |
| | 99.69 | | |

* Analysed rock is from N½ SW¼ NW¼ Sec. 20, T21N, R4E, M.D.B.M., elev. 1,200 feet.

It is suggested that the porphyritic basalt described above was emplaced as an intrusive, rather than extrusive, rock. Evidence which seems to support this view includes the lack in all parts of the mass of structural features which could be interpreted only as the result of eruption at the surface. On the other hand, the overall lithologic homogeneity observed in the mass and the textural features of the rock favor an intrusive origin. Again, an intrusive mode of emplacement is suggested by the sub-equidimensional shape of the mass as well as by the locally transgressive contact between it and the adjacent metasedimentary and metavolcanic rocks. Of course, the latter relationship might equally well be cited as evidence of an angular unconformity at the base of a section of extrusive volcanic rocks. If it is granted that the porphyritic basalt at Glover Ridge might be intrusive, the possibility also arises that the mass represents the lower part of a volcanic neck from which the basic extrusive rocks seen in certain nearby formations were, in part, erupted. The similarities with regard to chemical composition and petrography which exist between the porphyritic basalt of Glover Ridge and certain of the massive and fragmental rocks of the Oregon City Formation have been pointed out above. Because of these similarities and because of the fact that other possible eruptive centers for the Oregon City rocks were not found, the writer believes that the igneous mass at Glover Ridge probably represents one of the conduits from which such rocks were extruded. And if this is actually the case, the probable age of the porphyritic basalt would be Middle Jurassic. (See footnote, page 24.)

### Dikes of Various Rocks

Small dikes of various rocks have been injected into the bedrock terrane at many places. Most of these rocks apear to be of intermediate composition. They are particularly numerous in the northeastern part of the area. The most common type found there is a medium to light gray porphyritic andesite (?) in which slender, euhedral prisms of black or dark-brown hornblende, up to 5 mm in length, are scattered through a dominantly microcrystalline groundmass. The phenocrysts rarely constitute over 25 percent of the rock, and more often about 10 percent occur. Minute cubes of pyrite are often disseminated through the groundmass. As seen in thin-section, the groundmass is thoroughly altered to a dense, "saussuritic" complex of "sericite" and albite, with calcite, clinozoisite, and some epidote. The hornblende is a slightly pale green variety. This rock is massive and exhibits no sign of shear. It occurs in more or less planar dikes, measuring from 6 inches to several feet across, which transect the schistosity of the country rock. It thus seems likely that this rock was emplaced after the latest regional metamorphism of the enclosing rocks had occurred. A related rock may be the dark gray, somewhat altered andesite showing small, scattered phenocrysts of hornblende and plagioclase which occurs as a small plug-like body about a mile south and east of Serpentine Point. Under the microscope, the plagioclase proves to be sodic oligoclase. The microcrystalline ground mass contains, besides feldspar, abundant clinozoisite and some chlorite. A few percent of quartz, apatite, and sphene are present.

Fine-grained "saussuritized" hornblende diorite, which may have affinities with the dike-rocks described above, forms several relatively large dikes along the West Branch near the east edge of the quadrangle. The dikes range in thickness from 4 to 8 feet. Some of the rock contains rounded inclusions rich in dark-brown hornblende, while the material immediately adjacent to the inclusions is essentially devoid of ferromagnesian minerals and contains some quartz.

Another type of dike-rock is commonly exposed on this part of the West Branch. This rock is light greenish-gray or tan and consists of a microcrystalline, largely xenomorphic aggregate of calcite, "sericite", clinozoisite, chlorite, sphene, albite, and some epidote. The original rock was presumably of basic or intermediate composition. It occurs in dikes, up to 5 feet in thickness, which intersect the schistosity of the country rock at a high angle. Unlike the hornblende-bearing rocks described above, it possesses a well-defined schistosity which parallels that of the enclosing rocks, and was evidently emplaced prior to the final regional metamorphism to which the latter were subjected. Sharply angular chips of slate are included in some of these dikes, indicating that the original shale was at least well-consolidated, if not actually converted to slate, at the time the dike was injected.

A dark greenish-gray, porphyritic andesite intrudes the Oregon City volcanics just northeast of Thompson Flat. The rock is massive and has the form of a dike, 150 feet in width, which can be traced for nearly a mile. Abundant phenocrysts of plagioclase and a few prisms of hornblende are held in a tough, microcrystalline to aphanitic groundmass. Locally the hornblende occurs as broad phenocrysts up to 1 inch in length, but more often it is inconspicuous. Microscopic examination shows the feldspar (60-65$\%_c$) to be slightly clouded with minute inclusions of "sericite". The feldspar occurs both as short euhedral phenocrysts (30$\%$), ranging from 1 to 4 mm in length, and as microlites in a trachytic to pilotaxitic groundmass. Most of the feldspar is a rather acid variety of plaglioclase, possibly as sodic as albite-oligoclase. The hornblende (10-15$\%$) is greenish brown and is partly altered to chlorite. It is seen as subhedral prisms, and does not appear to be of uralitic origin. Small, rectangular aggregates of chlorite and quartz (?) are outlined and transected by sub-parallel trains of sphene. These constitute about 5 percent of the rock and are believed to be pseudomorphs after biotite. Chlorite is also commonly interstitial to the feldspar microlites in the groundmass. Epidote, apatite, clinozoisite, and quartz are present in trace amounts. A minor quantity of carbonate occurs in minute veinlets. From the mineral composition, it appears that the rock is a keratophyre or an andesite with strong keratophyric affinities.

## "Superjacent Series"

### Chico Formation

Nearly flat-lying fossiliferous marine sandstones underlie small areas near Pentz and in the canyons of Butte Creek and Little Butte Creek. These rocks are correlated on the basis of their distinctive lithology and faunal content with the Upper Cretaceous Chico Formation, whose type section lies but a few miles northwest of the Oroville Quadrangle.

The name "Chico" was first proposed as a group name by Gabb (1869, p. 129, footnote) who used it "for the beds of which Chico Creek, Pence's Ranch and Tuscan Springs are typical localities." Thus the deposits at "Pence's Ranch" (now Pentz) were apparently considered by Gabb to be an auxiliary type locality for the Chico. A more definite designation was given by Stanton (1896, p. 1013):

> The rocks . . . [on Chico Creek] . . . are now known to be Cretaceous, and this must be regarded as the typical locality of the Chico group, to which it [Chico Creek] gave its name.

Since the term "Chico" was advanced by Gabb, it has been used in several ways which differ from its original usage, and has been the subject of considerable debate among workers concerned with the subdivision of the California Cretaceous. Whitney (in Gabb, 1869, pp. xii-xiv) stated:

> The Chico group is one of the most extensive and important members of the Pacific Coast Cretaceous. Its exact relations with the formation in Europe have not yet been fully determined, though it is on the horizon of either the

> Upper or Lower Chalk, and may probably prove to be the equivalent of both . . . . It includes all of the known Cretaceous of Oregon and of the extreme northern portion of California . . . .

Stanton (1893, pp. 245-256) apparently initiated the practice of using "Chico" as a formational name rather than a group name. This usage has also been followed in all of the U.S. Geological Survey's folios in which the Chico was mapped. Diller and Stanton (1894) used the term "Chico" both as a formational (or group) name and as part of the name for a whole series which included all of the Cretaceous deposits in California—the "Shasta-Chico series". They noted (p. 444):

> The strata exposed at these localities [Pentz, Chico Creek, and other localities along the eastern border of the Sacramento Valley] are comparatively thin, and on structural grounds they are correlated with the upper portions of the beds referred to the Chico in the sections on the west side of the Sacramento valley. This correlation is supported by the fact that the few fossils, such as *Ammonites (Schloenbachia) chicoensis* and *Nucula truncata*, found only in the upper parts of these sections, are common at the typical localities above referred to, though the very small number of species makes the comparison with the rich fauna of the east side of the valley less satisfactory than is desirable. On the other hand, the lower 1,000 feet of the Chico in the measured sections * are very fossiliferous, and the fauna they have yielded, though not as large as that of the typical Chico localities, has many species in common with it, together with some that have not been found there.

Anderson (1937, p. 1612) designated a series, including the Upper Cretaceous deposits in California and Oregon, by the name "Chico"; he stated:

> These Upper Cretaceous deposits make up the Chico series. It is nowhere found in a single section, but on the whole aggregate 25,000 feet or more in thickness . . . . The Panoche group, including the Chico Creek . . . beds, has characteristic faunas in its upper one-third, but its lower and major part is barren.

Taff, Hanna, and Cross (1940), realizing the need for some adequate definition of the term "Chico", made observations and collected fossils on Chico Creek and in other nearby areas where Cretaceous rocks are exposed. They found (p. 1316) that "the areas of Chico strata exposed in Chico Canyon are more extensive and more accessible than in any other locality in the vicinity of Chico" and concluded (p. 1312) that "Chico Creek must be considered the type locality in any discussion of the rocks which bear that name."

The largest part of the area of study underlain by the Chico Formation lies in the low, rolling hills just southwest of Pentz. A somewhat smaller area of Chico exposures lies on the opposite side of Dry Creek, at the lowest part of the northwest slope of North Table Mountain. Because most of the formation is composed of rather friable sandstone, the slopes in these areas are usually mantled by soil, and outcrops are restricted to the banks of innumerable small gullies eroded into hillsides. The Chico Formation also crops out rather poorly along Butte Creek and Little Butte Creek, in the northwestern quarter of the quadrangle. It lies at the bottom of these canyons, and is overlain by upper Tertiary sedimentary and volcanic rocks. Recent stream gravels and talus from the steep-sided interstream ridges tend to mask the Chico, so that outcrops are more or less limited to the banks immediately bordering upon the creeks. Large fragments of gray Chico sandstone and siltstone, too soft to have been transported far, are abundant among the dredge-tailings on Little Butte Creek, where the Chico apparently served as false bedrock for the dredging operation.

The Chico Formation is characterized by light-colored, massive fossiliferous sandstone. It is usually yellowish-buff, pale greenish-buff, or light gray, although weathered outcrops may be white or orange-buff. Bedding is thin to thick, and cross-bedding is frequently observed. The more massive, finer-grained types tend to weather spheroidally. The sandstone is normally quite friable, but some thick, irregular beds are tightly cemented by calcite, especially in the vicinity of highly fossiliferous horizons. Grain-size ranges from very fine-grained to medium-grained, and individual strata tend to show fair to excellent size-sorting. Although siltstone and shale are interbedded with the coarser-grained sediments in places, the sandstone seldom contains any appreciable admixture of silt or clay.

Under the microscope, the sandstone is seen to be well-sorted and rather loosely packed. In the cemented varieties, microcrystalline calcite may make up to 50 percent of the rock and, very locally, the sandstone may grade into arenaceous limestone. The grains are dominantly angular to subangular, and consist chiefly of quartz (30%), feldspar (both plagioclase and orthoclase, 15-20%), unstable lithic fragments (especially slate and chlorite schist 15-20%), and detrital chert (10%). Minor but characteristic minerals may together total up to 15 percent and include biotite, green and blue-green hornblende, epidote, clinozoisite, and muscovite.

Thin lenticular beds of pebble to fine cobble conglomerate occasionally are interbedded with the finer-grained sediments. The pebbles are subrounded to well-rounded, and consist principally of light-to dark-colored chert, quartzite, altered quartz-bearing plutonic rocks, and porphyritic to non-porphyritic meta-igneous rocks. The conglomerate is usually hard and tightly cemented by calcite, and often contains abundant fragments of marine mollusk shells.

Pelitic sediments are relatively rare among the Chico rocks. Fragments of blue-gray, massive, firm, biotitic siltstone are abundant among the dredge-tailings along Little Butte Creek, but rocks of this type were not

* Diller and Stanton measured sections on Elder Creek, Tehama County, and on the North Fork of Cottonwood Creek, Shasta County, and observed the section on the Cold Fork of Cottonwood Creek, fifteen miles north of Elder Creek.

found in place there. A few poorly exposed outcrops of light tan, reddish-brown, or gray sandy shale and claystone occur near Pentz. Most of the pelitic types, however, occur as relatively thin partings in some of the finer-grained sandstone.

The majority of the Chico sediments contains fossils in one form or another. Poorly preserved and fragmentary plant-remains are often present on the bedding-planes in the finer-grained rocks. Fragmentary and complete molds and casts of the shells of marine mollusks are abundant in much of the sandstone, especially along bedding-surfaces in thin-bedded types. At a few localities original shell-material has not been leached away and is concentrated in irregular, calcite-cemented sandstone beds that grade locally into sandy coquina.

The Chico Formation, being the oldest unit of the "Superjacent series", rests with profound unconformity upon the beveled edges of the steeply dipping bedrock formations. The Cretaceous strata abut gently upon a westward-sloping bedrock surface which was formed in pre-Chico time. The contact cannot be directly observed within the Oroville quadrangle, since it is masked by younger sedimentary and volcanic rocks and by Quaternary alluvium. Taff, Hanna and Cross (1940, p. 1317) described the relations seen on Chico Creek northwest of Paradise as follows:

> At and near the base [of the Chico section] in Chico Canyon, the sandstone contains beds of conglomerate of dense and smoothly rounded quartzite, quartz, schist, and granitic rocks with the common sand matrix. . . . The Chico beds . . . [rest] . . . unconformably upon steeply inclined metamorphosed schistose shales and sandstone, [and] dip monoclinically at an average of 10 degrees approximately S 70° W. . . .

Next youngest to the Chico are the middle Eocene "Dry Creek" and Ione Formations, which directly overlie the Chico on the west side of Messilla Valley and on the west slope of North Table Mountain near Pentz. The contact is not exposed, largely because of the overall incompetent character of the formations involved, but may be mapped in detail sufficient to demonstrate that a marked disconformity exists between the two units. Both the Eocene and the Cretaceous strata dip gently toward the west, and when present elevations are corrected for this dip, a relief of at least 175 feet is found to exist upon the eroded upper surface of the Chico rocks. The Eocene sediments have filled the depressions in this surface.

Where Eocene beds are absent near Pentz and along Butte and Little Butte Creeks, the Chico is overlain with mild angular unconformity by the Pliocene (?) New Era Formation or Upper Pliocene Tuscan Formation. The relationship is best seen at Pentz. The younger strata dip rather consistently 1 or 2 degrees toward the southwest; the Chico beds vary considerably in attitude, but usually dip less than 5 degrees toward the west. Elsewhere, the Chico is overlain by Quaternary alluvium and related deposits.

The maximum exposed thickness of the Chico Formation in the Oroville quadrangle is found southwest of Pentz, where about 175 feet are exposed. The stratigraphic relationships of the Chico with the underlying bedrock surface suggests that the formation progressively increases in thickness toward the west, beneath the alluvial cover of the Sacramento Valley. This suggestion is supported by the fact that in all of the several gas wells drilled within or just west of the quadrangle, the Upper Cretaceous is considerably thicker than in the meagre outcrop section at Pentz. Just how much of the Upper Cretaceous strata had been stripped off prior to middle Eocene ("Dry Creek") time is not known. The Chico sediments have a distinctly near-shore, shallow water aspect, and the deposits at Pentz no doubt mark a site close to the shore line of a transgressing Upper Cretaceous sea. The higher parts of the area lying east of Pentz were emergent at the time these deposits were laid down, but it is not certain that they remained above sea level throughout Late Cretaceous time.

The top of the Chico Formation exposed in Big Butte and Little Butte Creeks dips gently toward the southwest at a slightly higher angle than that of the stream gradient, so that the thickness in the surface outcrops progressively increases upstream toward the northeast. Its maximum thickness on Little Butte Creek within the mapped area is about 60 feet. As noted above, a mild angular unconformity separates the Chico Formation from the overlying late Tertiary volcanic and sedimentary rocks. As a result of this unconformity, according to Taff, Hanna, and Cross (1940, p. 1317), the Chico is gradually overlapped by the younger rocks, and is cut out entirely on Butte and Little Butte Creeks several miles north of the northern limits of the Oroville quadrangle. Thus, while the thickness of the surface section increases toward the north, the total thickness of the formation, including the subsurface section, decreases in that direction. The thickness of the Chico at the type locality on Chico Creek is approximately 2000 feet.

Well-preserved marine fossils were found in the Chico Formation at several localities near Pentz. These were identified by Professor J. Wyatt Durham and are recorded in the check list below (Table 4). None were found in place in the area to the west although abundant fragments of fossiliferous sandstone are associated with recent terrace gravels along Butte Creek.

The fossiliferous Cretaceous strata at Pentz ("Pence's ranch" of early-day workers) have long been known and references to them appeared frequently in the older literature. The first list of species collected in the area was published by Gabb (1864, pp. 219-236), who listed 33 species for the locality. Subsequent lists, containing some forms not previously found, were published by Whitney (1865, p. 210), and by Turner (1894, pp. 459-460).

The latest published reference to the fauna at Pentz was written by Taff, Hanna, and Cross (1940, p. 1318), who stated:

> At the latter place [i.e. at Pentz] frontal erosion of the flow rocks has exposed Cretaceous rocks, and at all these nearby localities it has not been difficult to determine the fossil content of the sediment as Chico.

Durham*, after examining the fossils collected by the writer at Pentz, concluded that the rocks containing them are approximately the same age as the fossiliferous part of the type Chico. Popenoe (1943) subdivided the Upper Cretaceous sediments of the Redding

*Table 4. Check list of megafossils from the Chico formation. (Localities are described in appendix)*

| Locality number shown on geologic map | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| University of California Museum of Paleontology Locality Number | A-9443 | A-9444 | B-1245 | B-1246 | B-1247 | B-1248 | B-1249 | B-1250 |
| PELECYPODA | | | | | | | | |
| *Acila demessa* Finlay | X | X | X | | | X | | X |
| *Anomia* sp. | | | X | X | X | | | |
| *Anthonyia cultiformia* Gobb | X | | | | | | | |
| *Calva varians* (Gabb) | | | | | X | | | X |
| "*Cardium*" sp. | | | | | X | | | |
| *Corbula* sp. | | | | | | X | | |
| *Cucullaea* sp. | X | | | | | | | |
| *Cymbophora ashburneri* Gabb | X | X | X | X | X | X | | X |
| *Flaventia* sp. | X | | | | | | | |
| *Glycymeris veatchi* Gabb | | | | X | X | X | | ? |
| *Inoceramus* sp. | X | | | | | | | |
| "*Mactra*" sp. | | | | | X | | | |
| *Ostrea* sp. | | | | | | X | | |
| *Pinna* sp. | X | | | | | | | |
| *Septifer* sp. | | | | | | X | | |
| *Tellina ooides* Gabb | X | X | X | | | | | |
| *Tellina* sp. | | | | | | X | | |
| *Trinacria(?)* n.sp. | X | | | | | | | |
| GASTROPODA | | | | | | | | |
| *Acteonina(?)* sp. | | | | X | | | | |
| *Anchura falciformis* Gabb | | | | | | | | X |
| *Cinulia obliqua* Gabb | X | | X | | X | X | | |
| *Cylichnina* sp. | | | | | | X | | |
| *Gyrodes expansa* Gabb | | | | | | X | | X |
| *Gyrodes* sp. | X | | | | | | | |
| *Nerita* n.sp.(?) | | | | | | | X | |
| *Ptomides tenuis* Gabb | X | X | X | X | X | X | X | ? |
| CEPHALOPODA | | | | | | | | |
| *Baculites* sp. | | X | | | | | | |
| *Submortoniceras chicoensis* Trask | X | | | | | | | |
| SCAPHOPODA | | | | | | | | |
| *Cadulus* sp. | X | | | | | | | |

area into six members. Two distinctive sub-faunas are recognized as characteristic of the upper and lower parts, respectively, of the section. The younger sub-fauna is characteristic of the upper two members and a major portion of the third-highest member. The younger sub-fauna has among its "most abundant and characteristic forms" *Glycymeris veatchii* and *Gyrodes expansa*, both of which are also present in the collection from Pentz. Concerning this younger sub-fauna, Popenoe (p. 312) wrote:

> This faunal assemblage occurs . . . at Butte Creek and Chico Creek in Butte County, in the lower 200 feet of the Cretaceous section. The rather sparse collections obtained from horizons 200 to 1000 feet above the base of the section at Chico Creek can not at present be definitely correlated with any part of the Redding section but may represent some part of member VI [the youngest member recognized]. The faunas from horizons 1000 to 2000 feet above the base . . . are characterized by the appearance of many species not found at Redding. For this reason, the upper 1000 feet, and perhaps the upper 1800 feet of the of the Chico Creek section, are believed to be younger than any of the beds exposed in the Redding region.

Popenoe's statement is borne out by Taff, Hanna, and Cross (1940, pp. 1317-1318):

> The exposures on Chico Creek were found to form a unit without any stratigraphic break, and, since certain zones are highly fossiliferous, it would seem that correlation with other localities would be relatively simple. However, the contrary has proved to be the case. Either the assemblage of species represented there occupied peculiar environmental conditions and was, therefore, somewhat local in nature, or equivalent strata are not well known in other parts of California. It is obvious that the waters during the accumulation of these strata were purely marine in character and it is equally obvious that at least most of the sediments was derived from the subsiding land mass to the east.
>
> Unfortunately, the volcanic activity of the Tertiary covered much of the foothill country of the eastern part of the Sacramento Valley, and it is only where erosion has had a considerable effect that the underlying rocks may be seen. Thus only a few of the larger streams in addition to Chico Creek have cut through the mantle of volcanics. This is true of Butte Creek not far to the south and at Pentz's (older spelling "Penz" or "Pence") ranch, somewhat farther south. At the latter place frontal erosion of the flow rocks has exposed Cretaceous rocks, and at all these nearby localities it has not been difficult to determine the fossil content of the sediment as Chico.
>
> Northward from Chico Creek there is no such certainty of position. Characteristic fossils which would be expected to be present have not been found, and consequently the geological relationships remain obscure.

However, the difficulties of correlating the type Chico with Upper Cretaceous strata to the north are dwarfed by the complications which arise when a correlation with the rocks on the west side of the Sacramento Valley is attempted. In this regard, Taff, Hanna, and Cross stated (pp. 1318-1319):

> From Redding southward, along the west side of the Valley, conditions grow more and more obscure. The types of sediment have changed from those of Chico Creek, and fossils in those parts of the section where equivalent strata might be expected are nearly nonexistent. A good assemblage of fossils comparable to those of the Chico Creek localities has not been found in any place anywhere along the west side of the Sacramento-San Joaquin Valley border, a distance of about 400 miles, with many magnificently exposed sections.
>
> It might be expected that a well drilled somewhere out on the valley floor would furnish evidence which would

* Personal communication, 1954.

help to extend the Chico strata westward. Those which have been drilled have either been unfortunately located or for some other reason have failed to give information of the slightest importance in this problem. In a few cases, microfossils have appeared in the cores of the wells but they are neither abundant nor comparable with the fauna of the type locality. The writers were unable to find any microfaunas in the samples taken in Chico Creek.

Taliaferro (1943b, pp. 133-134) stated:

Thus far it has been impossible to correlate either the Pacheco or Asuncion groups [early and late Upper Cretaceous, respectively, in Coast Ranges] with the sediments of the type section of the Chico, on Chico Creek, Butte County, on the east side of the Sacramento Valley. About 2,000 feet of sediments are exposed in Chico Creek and there are said to be 12 fossiliferous horizons distributed almost from bottom to top. These sediments rest on highly metamorphosed Sierran bedrock and dip gently westward. Considering the fossiliferous character of these beds, it is strange that a more positive correlation with Upper Cretaceous sediments in other parts of the state has not been made. The faunas seem to be more closely related to the Pacheco than the Asuncion but there are some forms which are characteristic of the latter. This locality is more than 125 miles from any occurrence of either Pacheco or Asuncion sediments, as defined previously, and this might account for the difference in faunas. Although it is admitted that there is no very positive evidence on the subject, the writer is inclined to the belief that the sediments on Chico and adjacent creeks, the type section of the Chico, represents parts of both the Pacheco and Asuncion groups. The Chico Creek beds were deposited on the margin of the Upper Cretaceous basin, the rigid Sierran basement, where great thinning of the entire section would be expected, and in a region unaffected by the Santa Lucian orogeny [mid-Upper Cretaceous].

Undoubtedly it has been, in part, this natural lack of adequate paleontologic and lithologic criteria of correlation between the type Chico and other Upper Cretaceous rocks which has led to the widespread confusion regarding the proper use of the term "Chico". For it seems clear that had fossils or lithology or both been found in certain parts of other Upper Cretaceous sections which indicated a definite correlation between these parts and the type Chico, the term "Chico" would have been applied with a far greater degree of consistency than has been the case. The only ways in which a clarification of the nomenclature can be achieved are to either, as Taliaferro has suggested (1943b, p. 130), discard completely the term "Chico" or limit the term to a local formational (or group) name, giving priority to Gabb's original definition as it has been clarified by Stanton and by Taff, Hanna and Cross.

### "Greenstone Gravel"

The Cherokee hydraulic mine lies about 12 miles north of Oroville at the north end of Table Mountain. Millions of cubic yards of sediment have been removed by hydraulic mining methods. Mining here, except for the negligible work of "snipers", has long since ceased. But the bold cliffs left by the miners still stand today, and in them can be seen many of the details of the Tertiary sediments and lava which at other places are poorly, if at all, exposed. The main excavation trends slightly west of north parallel to the upper course of Sawmill Ravine and has an overall length of about a mile. At the north end of this excavation, a short segment of an ancient river channel has been partially exhumed by mining operations and by natural erosion (Fig. 21). Over much of this channel, the bedrock is overlain by coarse conglomerate and sedimentary breccia composed largely of cobbles and boulders of "greenstone" identical to that characterizing the underlying Oregon City Formation. These beds, because of their very limited distribution, have not been assigned a formational name. Instead, the writer, following the nomenclature employed by Lindgren (1911, p. 87) and Allen (1929, pp. 398-399), prefers to designate them by the colloquial but aptly descriptive term "greenstone gravel". Pettee (1880, p. 481) called them "blue gravel", and noted that they strongly resemble beds given that name in mines of Yuba and Nevada Counties. This unit is equivalent to at least part of what Lindgren (1911, p. 29) also termed "deep gravels".

The "greenstone gravel", because it is usually more or less consolidated, better fits the definition of conglomerate or breccia than that of gravel. It is extremely ill-sorted with respect to size (Fig. 22). Boulders up to 3 or 4 feet across are very often interspersed with more abundant cobbles and pebbles. Boulders of 6 or 7 feet in maximum dimension are common (Fig. 23), and several measuring 15 feet across have been observed. The boulders and cobbles are largely sub-angular, and many of them show incipient rounding. They consist mostly of grayish-green bedded tuff or volcanic sandstone, lapilli tuff, and tuff-breccia, identical in all respects to the underlying bedrock (Oregon City Formation). Cobbles and boulders of vein-quartz are locally abundant. Pebbles and cobbles of quartz and chert and a few of diorite and feldspar-porphyry accompany the predominant "greenstone". At most localities the matrix is quartz-chert-"greenstone"-pebble conglomerate, cemented by calcite or by iron oxide; at others the matrix consists of ill-sorted, olive-green argillaceous, biotitic, lithic sandstone and grit. Bedding in the conglomerate and breccia is usually obscure or lacking altogether, but at a few localities it is well-defined by interbeds of sandstone. At one point in Sawmill Ravine, several beds of dirty olive-green argillaceous, biotitic, lithic sandstone and calcite-cemented lithic grit are intercalated with the "gravel".

The "greenstone" cobbles and boulders are usually quite fresh. At some localities, however, especially in the upper part of the channel, they are strongly weathered and have been altered to yellowish-brown or reddish-brown clayey material. The cobble sizes seem to be most severely affected, but even the boulders

Figure 21. Aerial view of Cherokee hydraulic mine (Sawmill Ravine). Cherokee in foreground. Channel marked by broad line of tailings at lower left. Sugarloaf at left. In background is North Table Mountain capped by "older basalt". Note large columns of basalt beginning to topple, another already on side, and recent rockslide covering old landslide. Camera bears S. 25° W. *Photo by T. C. Slater, 1954.*

are encased in "rotten" shells. In this regard, Pettee (1880, p. 481) stated:

> Above the blue gravel there is a remarkable stratum, varying from three to ten feet in thickness, of the so called "rotten boulders". These have evidently been exposed to decomposing agencies, for though still retaining their shape, they contain a great deal of yellowish-red iron oxide, and are very easily broken up. The line between the rotten boulders and the blue gravel frequently passes through a pebble or boulder in such a way that the upper half has to be reckoned with one stratum and the lower half with the other.

Lindgren (1911, p. 87) noted that a "few feet of rotten boulders" lay above the fresh "greenstone gravel", and that they represent "simply decomposed gravels" from the material below. Allen (1929, pp. 398-399), discussing Lindgren's "few feet of rotten boulders", stated that they are "composed of boulders so decayed and soft that they could not have been transported without disintegrating." The bedrock in the upper end of the channel, unlike that found to the southwest, has been converted to red and yellow, soft, clayey lithomarge which, in places, exhibits relict bedding and cleavage inherited from the original rock. The decomposition of the "greenstone gravel" and of the underlying bedrock are attributed to the deep chemical decay which, as Allen (1929, p. 383-390) pointed out, preceded the deposition of the Ione Formation. It follows that the "greenstone gravel" itself must have been deposited prior to the pre-Ione period of chemical weathering.

The "greenstone gravel", because it covered an irregular, hummocky bedrock surface, varies rapidly in thickness from place to place. The maximum exposed thickness, about 40 feet, occurs at the collar of the main drainage shaft in Sawmill Ravine, but since the base is not exposed there, the total thickness may be much greater. At most places, however, the thickness does not exceed 15 feet.

The "greenstone gravel" is overlain by quartz-kaolinite * sandstone and conglomerate of the middle Eocene "auriferous gravels". The contact between the two units was observed on the northwest side of the

* The present writer uses the term *kaolinite* as an abbreviation for any member of the kaolinite-anauxite series proposed by Ross and Kerr (1931). The members of the series are, so far as known, indistinguishable from one another except through chemical analysis or X-ray studies.

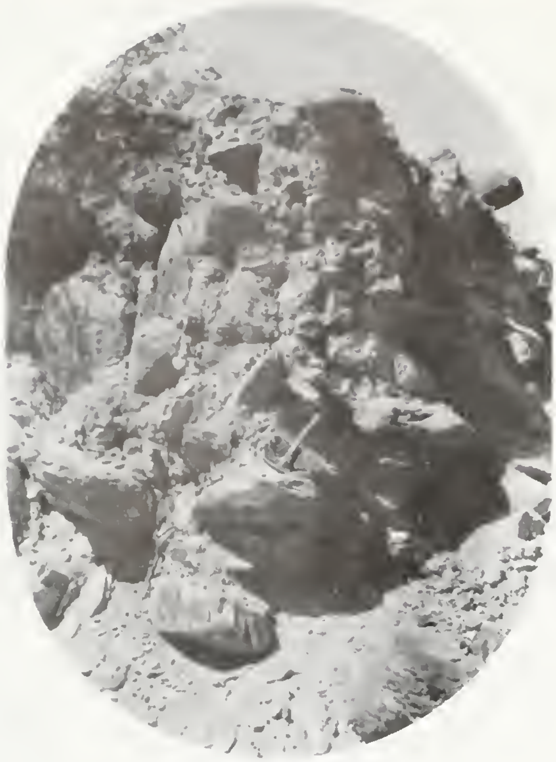


Figure 22. "Greenstone gravel", Cherokee mine.

ancient river channel described above. There, about a foot of gray, argillaceous sandstone lies above "rotten greenstone gravel", and is gradational with the matrix of the "gravel". The upper few inches of the sandstone are stained orange and are capped by a thin, undulating crust of iron-oxide. The crust is in turn overlain by sandstone and conglomerate typical of the lower part of the "auriferous gravels". The contact is interpreted as a slight erosional disconformity.

In several of the biotitic sandstones which are interbedded with the "rotten greenstone gravel", the biotite is accompanied by scattered flakes of what appears to be kaolinite. It is suggested that the kaolinite, rather than being detrital, as it is in the overlying "auriferous gravels", was formed in place at the expense of part of the biotite. The alteration would presumably have taken place at the time the enclosing "greenstone gravel" was also weathered. Allen (pp. 387-388) described anauxite in a deeply weathered biotite-hornblende granodiorite near Nevada City, and presented evidence which indicated that the anauxite there had formed from the biotite.

That the "greenstone gravel" was deposited in a stream channel is beyond question. It is restricted to a long, southwest-trending, trough-like depression cut into the underlying bedrock. The width of the depression varies between 800 and 1400 feet. It slopes approximately 200 feet per mile southwestward. The upper end has been eroded away so that a projection of the channel toward the northeast passes off into space. The lower end is covered by later sediments. The bottom of the depression has an overall flatness, but in detail is very hummocky, and exhibits such features as fluting and potholes in abundance. The "greenstone" boulders and cobbles show little, if any, rounding and are composed of material derived from the same bedrock volcanic formation which at present directly underlies the "gravel". This, combined with the unusually large size of the clasts, indicates that the material composing the "gravel" was subjected to very little stream-transportation. Instead, the writer considers it likely that the cobbles and boulders were emplaced in their present positions largely as talus and rockslide material derived from steep hillsides which once rose from the edges of the channel. Bedrock slopes as high as 30 degrees exist today at the edges of the channel, and these may have been even greater when the stream was active. On the other hand, the finer-grained material which now fills the spaces between the clasts—largely quartz sand and pebble-gravel—is no doubt the product of stream transportation and rounding. It may well have been carried considerable distances from highlands lying in the drainage area of the stream and washed into the spaces between the larger clasts. At any rate, it seems doubtful that two types of sediment were ever transported together for any great distance.

So far as the writer is aware, no fossils have been found in the "greenstone gravel" at Cherokee so that a determination of its age must be based upon its stratigraphic position and inferred correlation with deposits of known age. Lesquereux (1888, pp. 28-31) described a fossil flora collected by J. S. Diller from the "deep gravels" near Susanville. Lesquereux regarded 15 species as being of Eocene age. Knowlton (1911, pp. 60-61) restudied the original collection, along with additional material from the Susanville locality, and concluded:

> It appears beyond reasonable question that the lower plant-bearing beds southwest of Susanville are probably below and slightly older than the typical auriferous gravels, hence are possibly in the Upper Eocene.

Figure 23. "Greenstone gravel" resting on irregular bedrock surface. Above pick is 6-foot block of "greenstone". North end of Cherokee channel.

Knowlton (p. 64) considered the flora of the "auriferous gravels" to be of Miocene age. Chaney (1932, pp. 299-301), however, pointed out that the "auriferous gravels" actually include beds ranging in age from Eocene to Miocene. Later MacGinitie (1941, pp. 1-4) stated that the "auriferous gravels" included rocks of lower Pliocene age. Thus Knowlton's statement, quoted above, regarding the age of the Susanville flora appears to shed little light on the present question.

Beds above the "greenstone gravel" at Cherokee yielded plant fossils almost certainly of the same age as a middle Eocene flora which occurs near Colfax. Thus it appears that the "greenstone gravel" here is no younger than middle Eocene. This conclusion is supported by the fact that the deposition of the "greenstone gravel" appears to have preceded the period of deep chemical weathering which antedated the Ione (middle Eocene). The relationships of these beds to the "deep gravels" at Susanville is not known; they may be correlative, although it seems unlikely that all of Lindgren's "deep gravels" throughout the Sierra are of exactly the same age. Lindgren himself (1911, p. 29) realized this possibility, for he stated:

> It is likely that these [deep] gravels are of Eocene age, and some of them along the Tertiary Yuba River may even be Cretaceous.

Allen (1929, p. 400) suggested the possibility that the "greenstone gravel" is correlative with the Upper Cretaceous Chico strata which lie to the west near Pentz.

The stratigraphic position of the "greenstone gravel" and the abundance of biotite in the finer-grained sediments interbedded with the "gravel" suggest that this unit is contemporaneous with either the Upper Cretaceous Chico Formation or the middle Eocene "Dry Creek" Formation. The abundance of quartz and chert pebbles in the matrix of the "gravel" may indicate an Eocene age, since quartz and chert are also the dominant materials in the conglomerate of the Eocene "auriferous gravels" and in the few pebbly beds found in the "Dry Creek" Formation.

### "Dry Creek" Formation

The name "Dry Creek Formation" was proposed by Allen (1929, pp. 368-369) for a thin sequence of gray shale and biotitic sandstone which underlies the Ione Formation at Oroville North Table Mountain. He stated:

> Above the Cretaceous are gray shales overlain by biotite sandstones. The actual contact was not observed owing to the soil which forms on the shaly portion. Apparently it was from these shales that Turner [1894, p. 459] collected casts of *Corbicula* determined first as an Eocene fresh- or brackish-water genus. The best section is exposed in the steep-walled valley formed by a tributary of Dry Creek. The lowest beds consist of gray shales with flakes of biotite and casts of Eocene fossils. These are overlain conformably by light-colored biotite sands containing fragments of wood and leaves. The sands are sufficiently consolidated so that the stream has cut a trench three or four feet wide in which it flows with a winding course and over a series of small falls. A continuous section of eighty feet is exposed, and lenses of gravel a few inches thick composed of quartz, siliceous rock, and weathered greenstone, with casts of fossils may be observed in several places. The beds dip southwest about 4°. Gray shales occur at a road-cut farther downstream, and if these belong to the same formation, it reaches a thickness of over 180 feet. The mineral composition is shown . . . and the biotite, plagioclase, and orthoclase give little evidence of the weathering which has removed these minerals from the Ione assemblage. The name Dry Creek formation is suggested for these beds, from the tributary along which the section is displayed. At Coal Creek, the lower three feet of biotite sands that are exposed belong to this formation. At the lower part of Chamber's Ravine four feet of biotite gray shale is overlain by two feet of glauconite-anauxite sandstone containing casts of fossils. Some of these are similar to the forms reported by Dickerson [1916, p. 388] from the Dyer shaft one and one-half miles farther south. Dickerson states that his collection came from "dark gray shales interbedded with lignite containing fossiliferous strata, and thin-bedded fossiliferous sandstone." The matrix attached to some of the fossils from the shaft is very much like parts of the Dry Creek formation.

Unfortunately, the name "Dry Creek" was preempted before its use by Allen for the beds here under discussion (Wilmarth, 1938, p. 365). Stewart (1949, sheet no. 2) regarded the lower 50 feet of the Ione Formation at Marysville Buttes as being equivalent to Allen's Dry Creek Formation, and designated the lower beds at Marysville as the "Dry Creek" Sandstone Member of the Ione. Stewart stated:

> The lower part of the Ione [at Marysville] is a silty, micaceous, fine sandstone with plant remains and marine fossils. . . . The silty sand seems to grade up into the overlying white sands [Ione]—at least no obvious plane of separation was identified in the complete exposure . . . an apparently silty sand in a similar stratigraphic position has been described . . . near Oroville by Allen [1929, pp. 368-369] who named it the Dry Creek formation.

Because of the preoccupation of the term "Dry Creek", as pointed out above, Stewart used it in a quotational sense. For the same reason, the present writer will also use the term in a quotational sense, although he believes that the "Dry Creek" at Oroville should be considered not as a member of the Ione, but as a separate formational unit.

The "tributary of Dry Creek" to which Allen referred as the type locality of the "Dry Creek" Formation is apparently the small stream which flows southwestward from the northwest point of North Table Mountain, turns northwest, and merges with Flag Canyon, which then joins Dry Creek just west of the Oroville-Pentz road. The "Dry Creek" is fairly well-exposed along this stream, but outcrops to both the north and south are few. A few feet of strata of the "Dry Creek" crop out at the mouth of Coal Canyon, at the lower end of Schirmer Ravine, and at the base of the south slope of South Table Mountain, but because of their limited extent, it was impractical to map these outcrops separately from those of the Ione.

The lowest beds of the Superjacent series in certain parts of the Cherokee hyraulic mine also may be referable to the "Dry Creek" Formation, although mineralogically they differ somewhat from the typical "Dry Creek".

The "Dry Creek" Formation consists of interbedded sandstone, shale, claystone and siltstone, with a few minor beds of conglomerate and lignite. The most distinctive feature of these sediments is their high and almost universal content of biotite. Also highly characteristic is the general presence of thin bedding in both the sandstones and shales. The sandstones are usually light-colored; various shades of gray and buff are most common, although the beds may be locally stained orange by iron oxide. Thin alternations of two or more colors in a single unit of sandstone are common. For example, certain of the sandstones at the type locality are pale yellow and light gray in almost rhythmic alternations. Almost all of the sandstones are markedly thin-bedded. Bedding may be manifested by thin partings of clay-shale, by the concentration of large flakes of biotite along bedding planes, or by planar concentrations of fragmentary plant remains. None of the sandstone of the "Dry Creek" appears to be cemented, but most of it is somewhat firm due to the presence of abundant interstitial silt and clay. Grain-size is nearly always fine to very fine; a few feet of fossiliferous "Dry Creek" sandstone exposed at the base of South Table is fine- to medium-grained, but contains scattered coarse grains as well. Some of the "Dry Creek" sandstone is pebbly, and at several points small pebbles of gray claystone, apparently derived from the "Dry Creek" itself, are abundant. Scattered pebbles and granules of quartz and chert are found at a few localities. One thin stratum of pebble conglomerate containing small, rounded pebbles of white quartz is interbedded with the sandstone near the top of the formation at the type locality.

Megascopically, the only easily recognizable minerals in the sandstone are abundent quartz and biotite, and scatted grains of feldspar. Under the microscope, the sandstone is seen to be essentially feldspathic wacke. The grains are dominantly angular to subangular. They consist of quartz (45-50%), feldspar (both plagioclase and orthoclase, 15%), and biotite (5-10%), with minor quantities of detrital chert, muscovite, chlorite, green hornblende, epidote, sphene and zircon. The grains are rather loosely packed in a matrix of tan, microcrystalline clay of low birefringence. The matrix constitutes 30 to 40 percent of the rock. Glauconite makes up 15 or 20 percent of biotitic, argillaceous sandstone at the top of the "Dry Creek" in Schirmer Ravine. Some of the glauconite has partially replaced feldspar. As Takahashi (1939) has pointed out, glauconite is a product of submarine weathering. Its presence at the top of the "Dry Creek" suggests that a break in sedimentation without withdrawal of the sea may have occurred prior to the deposition of the overlying Ione sediments.

Light- to dark-gray clay-shale occurs as thin partings within larger sandstone units or as individual beds several feet in thickness. Some is quite pure, and apparently contains little else but clay. More often, however, the shale contains abundant flakes of biotite, with finely divided pyrite, concentrated along certain bedding-planes. Fragmentary remains of leaves or carbonized wood are also frequently present on bedding-planes and may be accompanied by small amounts of pyrite. At a few localities, the shale carries fish-scales and poorly preserved molds of small mollusks. The shale shows varying degrees of fissility; in places it is exceedingly fissile and flakes off into thin, paper-like sheets. At other localities, it exhibits only a widely-spaced, irregular fissility and grades into massive claystone. Much of the stratification in the shale is accentuated by the concentration of plant matter or biotite. At a few localities, thin beds of black lignite are interbedded with the normal detrital sediments.

At several points in the southern part of the Cherokee hydraulic mine (Sawmill Ravine) a few feet of alternating thin-bedded argillaceous sandstone and gray shale occur at the base of the Tertiary section. These sediments are biotitic and bear a superficial resemblance to the "Dry Creek" beds on the opposite side of Table Mountain. However, microscopic examination of the sandstone shows that it is much less feldspathic than the typical "Dry Creek" sandstone and that it contains, in addition to biotite, abundant kaolinite. Some of the kaolinite is interlaminated with biotite, suggesting that the kaolinite has formed at the expense of the biotite. Kaolinite is found rarely in the "Dry Creek" on the west side of Table Mountain, but is generally thought to be a characteristic mineral of the overlying Ione Formation (Allen, 1929, p. 376). Thus if the beds at the Cherokee mine are actually correlative with the type "Dry Creek" Formation, it may be that the kaolinite is of diagenetic, rather than detrital, origin. It is possible, for example, that the "Dry Creek" (?) beds at Cherokee were elevated and subjected to the deep chemical decay which preceded the deposition of the Ione (Allen, 1929, pp. 383-394), while the "Dry Creek" sediments to the west remained under water and were thus protected from subaerial weathering.

The maximum exposed thickness of the "Dry Creek" at the type locality is approximately 80 feet. The base of the formation is not exposed farther to the south and the thickness there may be much greater. Logs from Humble Oil and Refining Company's S. F. Brown *et al* No. 1 show a thickness for the Capay shale, presumably equivalent to the "Dry Creek", of approximately 120 feet.

The "Dry Creek" Formation in its type locality is underlain by the Upper Cretaceous Chico Formation. The actual contact was nowhere observed. No marked angular discordance exists between the two units, but the contact may be disconformable. Allen (1929, p. 400) suggested that a disconformity between the "Dry

Creek" and the Chico might exist, basing his reasoning "upon a single outcrop [of the "Dry Creek"] which appears to be lower than the top of the Chico". A similar observation was made by the present writer in the area north of Flag Canyon. At least some unconformity would be expected in light of the difference in apparent age of the two units, although complete vertical paleontologic control is lacking for either unit.

The "Dry Creek" is overlain by the Ione Formation on the west side of Table Mountain. The actual contact between the two was observed only at the type locality in the small canyon which lies just north of Flag Canyon. There, biotitic shale at the top of the "Dry Creek" is overlain by light tan argillaceous glauconite-kaolinite-quartz sandstone, thought to belong to the Ione Formation. The contact is sharply defined and irregular, showing a relief of at least 6 inches. A disconformable relationship between the two formations is also suggested by the fact that the "Dry Creek" beds do not extend north into the area where the Ione has filled a broad depression in the Upper Cretaceous strata. Either the "Dry Creek" strata are cut off disconformably by the Ione or they pass laterally into an Ione type of lithology. To the south, the "Dry Creek" crops out in only a few places. The best exposures in the southern area are in Coal Canyon and in Schirmer Ravine, and although the actual contact between the "Dry Creek" and overlying Ione cannot be directly observed at these places, it is thought to be conformable. At the mouth of Schirmer Ravine, a few feet of light brown argillaceous biotite-glauconite sandstone, apparently belonging to the "Dry Creek" formation, are overlain by sandstone of very similar appearance. However, the latter contains much less glauconite than the underlying unit, and kaolinite, rather than biotite, is the chief micaceous mineral. The overlying sandstone is presumably referable to the Ione Formation.

Identifiable fossils in the "Dry Creek" Formation were found by the writer at only two localities. At both places, invertebrate megafossils occur as fragmentary casts and molds only. The first locality (no. 3) lies on the northwest slope of North Table Mountain, about one-half mile north of Flag Canyon, and the fossils there are found in gray biotitic shale. Dr. L. G. Hertlein identified "*Corbicula*" sp., *Lima* (?) sp., *Cardium* (?) sp., a Venerid, possibly *Pitar* sp., and a gastropod somewhat resembling the species described as "*Metula harrisi*" Dickerson. Dr. Hertlein noted that the casts "suggest an Eocene faunule possibly somewhat similar to that of the Capay [middle Eocene]". The second locality (no. 2) is at the base of the south face of South Table Mountain. The fossiliferous rock there is pebbly biotitic argillaceous sandstone. Professor J. Wyatt Durham identified *Turbinolia* sp., *Acila* sp., *Spisula* sp., *Schedocardia* sp., *Corbula* sp., and *Fusus* sp. Professor Durham stated that the assemblage is "definitely Eocene in age, and is probably lower Eocene". The two localities, apparently yielding conflicting evidence as to the age of the "Dry Creek", are separated by over 6 miles, and since the formation cannot be traced continuously over that distance, the detailed stratigraphic relations between the two fossiliferous horizons cannot be determined. However, since the age determination for either locality is of a tentative nature, owing largely to the poor preservation of the fossils, the conflict between the two may be more apparent than real. At any rate, the two collections seem to definitely place the "Dry Creek" in the Eocene.

The work of Dickerson shed considerably more light upon the age of the "Dry Creek". Dickerson (1914, pp. 23-24) published a list of fossils collected at University of California locality no. 2225, described as being "beneath the Older Basalt of South Table Mountain in a locality about two miles north of Oroville". These Dickerson thought to belong to his "Siphonalia sutterensis zone", first recognized in the Eocene section at Marysville Buttes (Dickerson, 1913, pp. 270-272). Dickerson stated (1914, p. 24):

> The striking difference between the fauna at Oroville and that of the Marysville Buttes is the absence [at Oroville] of such forms as *Trochocyathus striatus* (Gabb) and *Schizaster lecontei* Merriam and of glauconite. . . . The fauna of the South Table Mountain Eocene is merely a different facies than that of the Marysville Buttes and the absence of the coral, echinoderm, and glauconite mentioned above is due to differences in bathymetric conditions. The South Table Mountain Eocene was deposited under littoral conditions, while that of the Marysville Buttes was deposited in considerably deeper water. The differences in lithology confirm this conclusion. These faunas are of approximately the same age, but deposited under quite different conditions.
>
> A surface outcrop somewhat higher than that described as locality no. 2225 yielded *Barbatia morsei* Gabb, *Meretrix hornii* Gabb, *Paphia* (?) sp., *Placunanomia inornata* Gabb, *Turritella merriami* Dickerson, and *Ostrea* sp. The presence of wood and lignite suggests that this fauna was deposited in brackish water.

In a later paper Dickerson (1916, p. 394) wrote:

> The evidence stated above [referring to Dickerson's earlier paper, quoted above] demonstrates the Eocene age of the sediments beneath the Older Basalt, [and] correlates these beds with the Siphonalia sutterensis zone of the Marysville Buttes region. . . .

A stratigraphic section at South Table Mountain was measured by Dickerson (1916, p. 390):

> A study of the sediments as exposed in the Dyer shaft and the south face of South Table Mountain gives in descending order the following approximate sequence:

| | Feet |
|---|---|
| (9) Older basalt | 100 to 150 |
| (8) Andesitic tuff breccia | 10 to 20 |
| (7) Alternating sandstone, clay, and carbonaceous shales | 100 |
| (6) Conglomerate | 50 |
| (5) Tuffaceous clay | 20 |
| (4) Yellow, tan sandstone | 100 |
| (3) Dark gray shales interbedded with lignite containing fossiliferous strata, and thin-bedded fossiliferous sandstone | 40 |
| (2) Clay with tuff fragments | 20 |
| (1) Conglomerate resting upon Chico sandstone | 20 |

Allen (1929, p. 369) has alluded to the fact that Dickerson's 40 feet of "dark gray shales interbedded with lignite containing fossiliferous strata, and thin-bedded fossiliferous sandstone" are probably referable to the "Dry Creek" Formation. Allen (pp. 370-372) has further shown that the lowermost two units of Dickerson's section are actually Quaternary sediments which occupy benches cut into the Eocene, while the "Chico sandstone" to which Dickerson referred belongs to the Monte de Oro Formation, a bedrock unit. Merriam and Turner (1937, p. 94) considered Dickerson's "Siphonalia sutterensis zone" to be equivalent to a part of the Capay stage (middle Eocene). Thus the "Dry Creek" is apparently middle Eocene.

### Ione Formation

A succession of distinctive light-colored sandstone, varicolored claystone, and siltstone underlies the foothills north of Oroville where the slopes merge with the gently rolling plain of the Sacramento Valley. These rocks are referred to the Ione Formation (Eocene), whose type locality lies 80 miles to the south, near the town of Ione.

The Ione Formation was named by Lindgren (1894, p. 3), who stated:

> During the Neocene [the Ione was then believed to be Miocene in age] period the auriferous gravels accumulated on the slope of the Sierra Nevada, and at the same time there was deposited in the gulf then occupying the Great Valley a sedimentary series consisting of clays and sands, to which the name *Ione Formation* has been given.

Turner (1894, p. 4) described the Ione at the type locality, where he divided the formation into three members:

a) A lower white clay, in some places sandy, in others relatively pure (Turner mentioned that this clay was thought by some to have formed from rhyolite tuffs).

b) Sandstone, usually white but locally brick-red; in places contains white quartz pebbles, passing into conglomerates.

c) Clay rock, fine-grained, light gray, with irregular fractures.

The Ione Formation lying beneath the basalt at Oroville Table Mountain was briefly described by Turner (1894, p. 463). A reconnaissance geologic map of part of the Oroville quadrangle, showing the approximate areal distribution of the Ione Formation there, was published by Lindgren (1911, Pl. 15, p. 86) in his classic paper, *The Tertiary gravels of the Sierra Nevada of California*. Dickerson's (1916, pp. 388-394) remarks regarding the Eocene strata of the Oroville area have been cited above; however, it should be emphasized that all the fossils he collected at South Table Mountain apparently came from the "Dry Creek" Formation rather than from the overlying Ione. Thus his statements, while they shed light on the lower age limit of the Ione, did not restrict the upper age boundary.

An extensive regional study of the Ione Formation was carried out by Allen (1929), who realized (pp. 353-354) that the term Ione Formation "has been employed in a number of different ways and to include a variety of unrelated rock types"; he proposed a redefinition of the term:

> In the present paper, it is proposed to restrict the name Ione formation to the beds along the foothills of the Sierra Nevada that have a mineral composition and history similar to the lower two members [previously listed by Turner (1894, p. 4)] of the type locality.

The most recent significant contribution to the study of the Ione Formation is that by Pask and Turner (1952), who mapped and described in detail a small area of Ione in the southern part of the type locality in Amador County. In their study, the Ione (as restricted by Allen) is divided into two members, distinctly different in mineralogic character and separated by an unconformity.

The largest area underlain by the Ione Formation in the Oroville quadrangle lies on the western slopes of North and South Table Mountains. Smaller areas of Ione occur in Messilla Valley, near Pentz, on the hills southwest of Wicks Corner, and on the northeastern end of the Campbell Hills. Outcrops of the formation are rather limited at these localities because the Ione is usually overlain by volcanic rocks or aproned with numerous rockslides. The best, and sometimes only, exposures lie along the bottoms of the larger ravines which run westward from the top of Table Mountain. Principal among these are Flag Canyon, Coal Canyon, and Schirmer Ravine (formerly Chambers Ravine). Small parts of the section are well-exposed in several hydraulic mine faces near Pentz and in a clay quarry near Wicks Corner.

The exposures of Ione lying in the Oroville quadrangle probably mark the northernmost areal extent of the formation. Although Diller (1906, p. 6) mapped sediments lying above the Chico and below the Tuscan in the Redding quadrangle as Ione, Allen (1929, pp. 374-375) has shown that these deposits are in no way similar to the Ione and are probably Cretaceous in age. According to Cross, *et al.* (1954), the Ione was encountered in Richfield Oil Corporation's Dayton Community two—1 well (sec. 6, T. 21 N., R. 1 E.), about 4 miles southwest of Chico, but the formation was not recognized in wells drilled north of that point.

Light-colored argillaceous sandstone and claystone together constitute perhaps more than 75 percent of the Ione in the Oroville quadrangle. Intercalated with these are subordinate amounts of siltstone, shale, and conglomerate, and a few minor beds of lignitic coal. Most of the Ione sediments are rather soft, and usually weather to gentle soil-covered slopes or to a poorly developed "badland" topography.

The Ione sandstone is typically white or yellowish-white streaked with orange, but in many places sufficient ferruginous matter is present to stain entire outcrops buff or pale orange. Bedding tends to be poorly defined, but many of the sandstones found in the lower 70 feet of the section at Schirmer Ravine are markedly thin-bedded and vary in color from light gray to light tan. Well developed cross-bedding occurs at a few localities, but does not appear to be characteristic of the formation as a whole. The bulk of the Ione sandstone is medium-grained, although very fine-grained or very coarse-grained variants are common. The degree of sorting with respect to size of grains is generally only moderate. Most of the grains are angular to subangular, and sharp splinter-like fragments occur frequently. Scattered well-rounded pebbles of quartz or chert occur in the sandstone, and thin, lenticular strata of pebble-conglomerate are found at several localities. A characteristic feature of most of the sandstone is its extremely argillaceous nature. Medium- and coarse-grained sandstone is usually uncemented and friable, and is consolidated only because it contains interstitial silt and clay. Finer-grained varieties, however, are often firmly bonded by abundant argillaceous material. At several localities, dark brick-red sandstone is tightly cemented by iron oxide.

High content of angular quartz grains is perhaps the most characteristic property of the Ione sandstone. Feldspar occurs in very minor quantities and constitutes no more than 10 percent of the grains in most cases, although some of the sandstone in the upper part of the formation is slightly more feldspathic. Most of the sandstone in the lower part of the Ione contains abundant flakes of a white, pearly micaceous mineral. Microscopic examination shows that it is not mica but kaolinite.* Undoubtedly it was kaolinite to which Turner (1894a, p. 4), discussing the sandstone in the Ione at the type locality, referred as "a peculiar hydrous silicate of alumina which occurs abundantly in the sandstone in the form of cream-colored, pearly scales."

Sandstone in the upper part of the Ione Formation at Oroville contains some kaolinite, but the principal micaceous mineral in the specimens examined is weathered biotite. A few feet of biotitic quartz sandstone are intercalated with quartz-kaolinite sandstone about 70 feet above the base of the Ione in Schirmer Ravine. In the same section, minute pellets of glauconite are abundant in a thin-bedded kaolinitic sandstone about 15 feet above the base of the formation. Glauconite also occurs in association with kaolinite at the base of the Ione north of Flag Canyon.

As seen under the microscope, the sandstone of the Ione consists of loosely packed angular to subangular grains of quartz, detrital chert, and minor feldspar, set in a prominent clay matrix. The matrix, which constitutes from 25 to 40 percent of the rock, is a dark tan, microcrystalline material of very low birefringence. In places, it contains minute crystals of kaolinite, which appear to have formed by authigenic processes from the matrix clay. The most common non-opaque heavy minerals are epidote, zircon, tourmaline, clinozoisite, and andalusite. A quartz-kaolinite sandstone from the hills southwest of Wicks Corner is exceptional in that it contains, among the heavy minerals, little besides opaque minerals and euhedral zircon. Green hornblende, the next most abundant non-opaque heavy mineral to biotite in the underlying "Dry Creek" and Chico Formations, occurs sparingly in most of the sandstone in the lower part of the Ione. Sandstone in the upper part of the Ione on South Table Mountain, however, contains biotite and hornblende as the chief heavy minerals.

Claystone is perhaps more abundant than sandstone in the Ione Formation, but because of its extremely non-resistant nature, it tends to form fewer outcrops than the sandstone, and thus is less conspicuous. Claystone is particularly abundant in the upper half of the formation. It is usually interbedded as thick beds with sandstone, although Dietrich (1928, p. 66) reported that one drill-hole in the clay deposit near Wicks Corner "was drilled to a depth of 72 feet without encountering a change of formation." The claystone exhibits a variety of colors; white or very light gray is probably the most common, and mottled color patterns, combining orange with white or red with cream-yellow, occur frequently. Colors less often observed include light gray, light tan, and light brown. The claystone is usually massive, blocky, and is almost always soft and plastic. Much of it is rather pure and even-textured, but some contains a noticeable admixture of silt, and some carries a considerable percentage of sand. An interesting type occurring in Coal Canyon, near the middle of the section, is very light gray, nearly pure claystone which contains abundant and evenly disseminated angular grains of quartz. Allen (1929, pp. 379-382), discussing the Ione clays, found that there exists no evidence suggesting a derivation of the clays from tuff, as had been suggested by Lindgren (1894b, p. 3) and others. Allen noted that the Ione clays in the vicinity of Ione, at Lincoln, and at Valley Springs contain clay minerals belonging to the kaolin group, a conclusion since substantiated by Ross and Kerr (1930, pp. 161-164), Bates (1945, pp. 17-25), and Pask and Turner (1952, pp. 10-11).

In most parts of the Ione Formation of the Oroville quadrangle, clay-shale and thin-bedded siltstone are

* The present writer uses the term *kaolinite* as an abbreviation for any member of the kaolinite-anauxite series. Allen (1928) demonstrated the presence of anauxite in the Ione Formation and later (1929, pp. 376-377) considered anauxite to be "the most characteristic [light] mineral of the [Ione] assemblage" and to be "nearly always present" and in exceptional cases to constitute "more than half the sample". However, anauxite is closely allied both chemically and structurally with the mineral kaolinite and the two are, so far as known, indistinguishable except through chemical analysis or x-ray studies. Ross and Kerr (1931) suggested a series of kaolinite-anauxite. It is impossible to state as yet, on the basis of the few chemical analyses available, whether anauxite or some other member of the series is actually the characteristic mineral of the Ione Formation.

much less abundant than the sandstone and claystone with which they are interbedded. They are mainly restricted to the lower half of the formation. Most of the shale is rather dark, and its color is attributed, in part, to a relatively high content of carbonaceous impurities. Some of the darker varieties are intimately associated with the few beds of lignite which occur in the Ione. A thin bed of lignite cropping out in Coal Canyon about 100 feet above the base of the formation is both underlain and overlain by dark brown and dark gray plant-bearing carbonaceous shale. Other pelitic types locally encountered in the Ione are pale gray or pale tan, hard, platy kaolinitic clay-shale and clayey siltstone.

Of interest are two thin lignitic horizons occurring in the lower part of the Ione section at Coal Canyon. The stratigraphically higher of the two, lying about 100 feet above the base of the formation, is 4 feet thick. It is black, massive, and exhibits a sub-vitreous luster. Solid fresh pieces fracture spontaneously into angular fragments upon exposure to the air. Under the hand lens, the lignite shows a finely striated, woody texture. The second lignitic horizon lies about 25 feet stratigraphically below the latter. Brown lignitic shale, carrying abundant plant fragments, is interbedded with white and red kaolinitic sandstone and crops out at the surface. Lignite was apparently mined at an early date, for a shaft was sunk at the locality. The shaft is caved, but the dump contains abundant fragments of black, fissile, woody lignite. This deposit may be the same as that described by Watts (1893, p. 166), who stated:

> Coal was mined at an early day near Oroville, on the property of C. F. Lott; a tunnel being run in for about 35 feet and the vein drifted on, for, it is said, several hundred feet. The vein is reported to have been about 6 feet thick. This coal was used during the 70's at Oroville, both for fuel and for making gas. It is said to have burned well, and the gas made from it to have been of good quality.
>
> A few yards from the tunnel, and at a slightly lower elevation, a boring was made to the depth of about 25 feet. The formation was bluish clay, which is said to have yielded gas in the retorts. At a depth of 25 feet, a bright looking coal was struck, which burned well; but this coal stratum was not bored through.

The Ione beds mapped in Messilla Valley, north of Pentz, crop out rather sporadically, but what few exposures can be found indicate that dark-colored clay-shale is more abundant than in sections lying farther south. The shale bears a superficial resemblance to some of the darker shale of the "Dry Creek" Formation, but is interbedded with quartzose sandstones of typical Ione aspect. Furthermore, the shale in Messilla Valley contains no appreciable quantities of biotite, a mineral conspicuous and ubiquitous in the "Dry Creek" sediments. Some of the shale in Messilla Valley is very dark gray or nearly black, and contains abundant minute fragments of carbonized plant matter. It may be in part correlative with the carbonaceous shale and thin lignite beds occurring in the Coal Canyon section.

About 90 feet of nearly flat-lying strata are exposed on one side of a small, isolated hill about one mile east of Pentz. The lower half of the sequence consists of light-colored agrillaceous quartz-kaolinite sandstone and interbedded dark gray shale. These sediments are similar to those mapped as Ione in Messilla Valley and are themselves referred to the Ione. The overlying beds, however, consist of pale pinkish-tan, punky shale of a type not found in any other Tertiary section in the area. They are quite sandy toward the base, and the contact with the underlying Ione sediments is sharp and somewhat irregular, suggesting a disconformable relationship. The pink shale contains abundant casts of leaves (Locality 14). Specimens of the latter were submitted to Professor R. W. Chaney, who identified them as *Cunninghamia* sp. and *Sabalites* sp. *Sabalites* ranges from Paleocene to Oligocene in age, while *Cunninghamia* has been found, in North America, only in the Eocene of Colorado (Lamotte, 1952). The excellent preservation of the delicate leaves may indicate that the enclosing sediments accumulated in quiet, perhaps lacustrine, waters. These strata are questionably referred to the Ione, and may represent a local facies of that formation.

Allen (1929, pp. 375-382) carried out an extensive study of the minerals which occur in the Ione and concluded that the source of the sediments lay to the east in the Sierra Nevada. Similarly, Bates (1945, pp. 28-30) believed that the bulk of the quartz grains in certain of the clays at Ione had been derived from granitic intrusives in the Sierra. Lindgren (1911, p. 24) postulated that the Ione Formation represents deltaic deposits which accumulated at the mouth of Tertiary pre-volcanic Sierran streams which flowed down the western slope of the range. He stated:

> During the Miocene [the fossils which placed the Ione in the Eocene had not yet been found] and contemporaneously with the accumulation of the later pre-volcanic gravels on the slopes of the Sierra Nevada there was deposited in the gulf then occupying the Great Valley a sedimentary series of clays and sands to which the name Ione Formation has been given. The water in this gulf was probably brackish; no marine fossils have been found in the Ione Formation at the foot of the range, but fossil leaves, vegetable material, and, in places, coal are abundant. At the mouth of the rivers which descended from the Tertiary Sierra Nevada extensive delta deposits were accumulated, and it is thus difficult in many places to draw any exact line between the Ione formation and the river gravels proper. . . . At many localities the sandstones and clays of the formation merge directly into the upper river gravels of the so-called benches.

Allen (1929, p. 404) concurred with this view and likened the lenses of gravel, the carbonaceous material, and the variety of colors which occur in the Ione to similar features observed in modern delta deposits. He correlated the Ione sediments with certain of the Sierran "auriferous gravels" (specifically the white quartz gravels) on the basis of conclusive mineralogic and stratigraphic evidence.

The sediments which constitute the lower part of the Ione Formation in the Oroville area are composed of a relatively stable mineral assemblage. Especially significant in this regard are the marked abundance of quartz and clay minerals and the paucity of such less stable minerals as feldspar and biotite. The Ione sediments thus stand in direct contrast with the rocks of the underlying "Dry Creek" and Chico Formations. Allen (1929, pp. 375-382) concluded, on the basis of the overall mineralogic maturity of the formation throughout its geographic extent, that "the Ione assemblage is characterized by minerals that are resistant to chemical decay and the evidence is strongly suggestive that chemical weathering has been largely responsible for the individuality attained by the Ione sediments." He believed that the angularity and euhedralism of many mineral grains prohibited the possibility of long distance transport or reworking to account for the removal of the less stable minerals. The supposed chemical decay of the source rocks of the Ione was attributed by Allen (pp. 383-394) largely to a prevalence during immediately pre-Ione time of tropical or subtropical climatic conditions. In support of this conclusion, Allen cited: (a) the widespread production on the pre-Ione surface of a part of the typical lateritic profile, supposed to characterize weathering in tropical climates, and (b) the paleontological evidence, both floral and faunal, which indicates that "the climate of the pre-Ione Eocene was tropical or subtropical." The development of a deep lateritic profile implies that erosion, except perhaps in actual stream channels, was at a minimum.

Allen (pp. 403-404) considered that the deposition of the Ione sediments began after uplift and erosion interrupted the weathering process and "commenced to strip off the products of rock decay". Under such conditions, the earliest deposits would be derivatives of the more severely weathered parts of the source rock, and the mineral assemblage contained therein would, on the whole, be of a stable nature. The character of the Ione mineral assemblage substantiates this inference. On the other hand, the assemblage which constitutes the sandstone in the upper part of the Ione at Oroville is less stable than that found in the lower part, and may thus represent material derived from less-weathered parts of the profile which became accessible as erosion progressed. A similar conclusion with regard to the uppermost parts of the Ione at Valley Springs and at Knights Ferry was reached by Allen (1929, p. 406).

Pask and Turner (1952, pp. 16-20) subdivided the Ione Formation in the Buena Vista area, about 4 miles south of Ione, into two members which are clearly separated by an unconformity. The upper member "is characterized by a generally higher proportion of feldspar to quartz than in the lower Ione and by the presence of biotite, chlorite" and kaolinitic clay of somewhat different properties, with respect to differential thermal analysis, than that in the lower member. Pask and Turner (p. 22) noted that the "upper Ione sediments do not show as great a degree of weathering as do lower Ione sediments", and concluded that the difference "may have been due to a change to more temperate climate or to a change in the conditions of erosion".

The maximum exposed thickness of the Ione Formation in the Oroville quadrangle is approximately 600 feet. This thickness is exposed on the northwest slope of North Table Mountain, where the Ione appears to have filled a broad depression eroded into the "Dry Creek" and Chico beds. The Ione thus lies disconformably on both of these formations, but, as was suggested previously, may be conformable with the "Dry Creek" strata farther to the south. In other places, the thickness of the Ione does not exceed 350 feet. The Ione is overlain over most of its outcrop area, with slight angular discordance, by the "older basalt". In the southern part of the area, the Ione disconformably underlies the andesitic rocks of the Mehrten (?) Formation.

Except for the plants mentioned above, determinable fossils were not found in the Ione Formation by the writer. Abundant fragmentary plant matter occurs in many of the Ione sediments, and poorly preserved casts and molds of mollusks are found in a few of the more argillaceous rocks. As has been pointed out, Dickerson's remarks regarding the age of the strata at South Table Mountain are directly applicable to the "Dry Creek" beds, but not to the Ione strata which overlie them. However, the determination of the age of at least part of the "Dry Creek" as middle Eocene shows that the overlying Ione is no older than middle Eocene.

Since in the Oroville area the Ione definitely appears to be correlative with the middle Eocene "auriferous gravels", it follows that the Ione there is also middle Eocene. Determinable fossils have been found at relatively few localities in the Ione throughout the Sierran foothills, considering the rather extensive distribution of the formation. Dickerson (1916, p. 397) listed 5 species, including *Turritella merriami*, and 2 nonspecific genera found by him in the Ione a few miles southeast of the type locality, and stated that "while the fauna is a small one, it is typical of . . . the Siphonalia sutterensis zone . . . ." Merriam and Turner (1937, p. 94) believed that the "Siphonalia sutterensis zone" is equivalent to a portion of the Capay stage (middle Eocene). Thus the Ione at its type locality and in other areas, including Oroville, is probably middle Eocene.

#### "Auriferous Gravels"

The term "auriferous gravels" has long been applied to various gold-bearing superjacent strata which lie along the western slope of the Sierra Nevada. The name, used in this way, has become firmly entrenched

Figure 24. Aerial view of Cherokee hydraulic mine. Prominent joint-systems in "older basalt" are accentuated by differences in vegetation. White is grass, gray is bare rock. View S. 35° E. *Photo by T. C. Slater, 1954.*

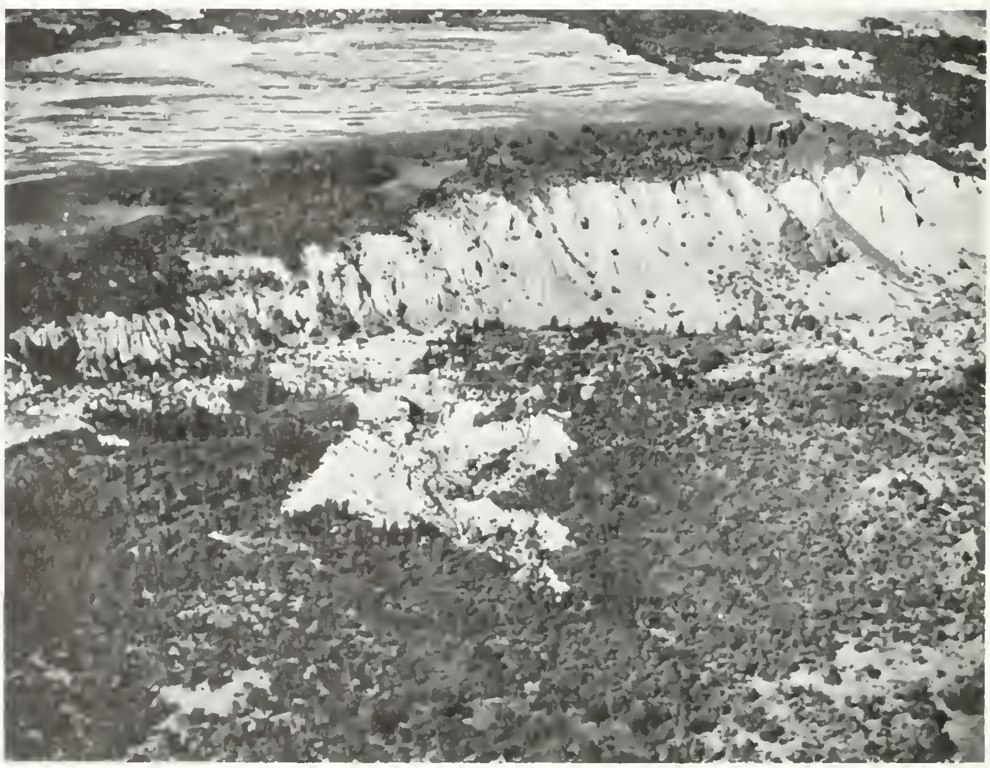


Figure 25. Aerial view of Cherokee hydraulic mine, showing "older basalt" and landslides. View S. 85° W. *Photo by T. C. Slater, 1954.*

in the geologic literature. Relating to the Sierra it has been used often in a formational sense, although it appears to have been generally applied to practically any sedimentary rock which contained placer gold, regardless of the lithology or age of the rock itself. Chaney (1932, p. 227) stated:

> It is clear that the Auriferous Gravels were deposited during a considerable portion of the Tertiary, ranging from Middle Eocene into the Miocene.

Chaney (1933, p. 78) later noted:

> Recent collections [of fossil plants] indicate that the age of these gravels [gold bearing gravels on the west flank of the Sierra Nevada] ranges from Eocene to Pleistocene.

The diverse usage of the term "auriferous gravels" was succinctly indicated by Wilmarth (1938, p. 92) who defined the "auriferous gravels" as "a descriptive term that has had considerable usage in northern California for gravels of Cretaceous, Eocene and Pleistocene age." Jenkins (1943, p. 673), regarding the "auriferous gravels", stated:

> In a restricted sense, the term refers to the older gravels; in this manner it has been used extensively; Eocene (middle and upper) to Miocene.

MacGinitie (1941, pp. 1-4) noted that rocks previously designated as "auriferous gravels" range in age from middle Eocene to lower Pliocene.

Certainly not all of the "auriferous gravels" at any one locality are composed entirely, or even predominantly, of gravel or conglomerate. In the Oroville quadrangle, for example, conglomerate and gravel make up only about 25 or 35 percent of the total section of strata which have been classified as "auriferous gravels" there. Nor is the lithology of the "auriferous gravels" at one locality necessarily similar to that at another, even though they may lie only a few miles apart. Indeed, sometimes the only common factors between the "gravels" at two different points are merely the presence of economic quantities of gold and the fact that both represent fluviatile deposits.

Subdivision of the "auriferous gravels" into valid units of member or formational status would no doubt serve to eliminate, at least in part, the confusion which exists regarding the term. The many relatively recent contributions to our knowledge of the age of the "auriferous gravels", made largely through the efforts of such workers as Allen, Chaney, MacGinitie, Axelrod, and Potbury, seems to warrant the undertaking of such a subdivision. Hinds (1933, pp. 115-116), working in the Klamath Mountains, proposed the term Weaverville beds for strata which had previously been classified as "auriferous gravels" by Diller (1894, p. 419).

As will be discussed more fully in a later section, the finer-grained sediments of the "auriferous gravels" at Oroville are in part identical with the sediments of the Ione Formation which occupies the same stratigraphic interval as do the "auriferous gravels". Not without some justification, Lindgren (1911, pl. 15, p. 86) mapped the sediments on the east side of Table Mountain as Ione. Allen (1929, fig. 5, p. 367) designated them as "Eocene Gravels" rather than Ione, pointing out, however, that they are correlative with the Ione to the west. Apparently Allen believed that the term Ione should be restricted to sediments which have a closer similarity to the type section in Amador County which, according to him (pp. 354-359), consists largely of sandstone and clay and contains only minor quantities of conglomerate or gravel. However, since the two formations are so closely related in age, mode of origin, and mineralogy, and differ significantly only in texture and percent of lithologic types, some definite link in the nomenclature of the two may be indicated. For example, the Ione Formation and the "gravels" which are definitely known to be closely related to the Ione in age and lithology might be bound together under an inclusive group name. No change in nomenclature is proposed here, however, since such a modification should be based on a regional study of both the Ione and the "auriferous gravels". Because of the factors cited above, the term "auriferous gravels" will be used in a quotational sense in the present paper and, unless otherwise indicated, will be applied as a formational name of only local significance.

The "auriferous gravels" crop out in two areas. One lies at the south edge of North Table Mountain, in Morris Ravine and at the head of Schirmer Ravine; the second and smaller area is at the north end of North Table Mountain, in the upper part of Sawmill Ravine and in the broad, flat-bottomed channel which lies south and east of the hamlet of Cherokee. In this second area are extensive old hydraulic workings, known colloquially as the "Cherokee hydraulic mine". It is in these workings, especially in the hydraulic faces themselves, that the "auriferous gravels" are most extensively and continuously exposed (Figs. 21, 24-26). Two small isolated areas of "gravel" were mapped between Monte de Oro and Oregon City.

Figure 26. West face of Cherokee hydraulic mine, with outcropping bedrock in foreground. View south from Cherokee.

The "gravels" are also well exposed at Morris Ravine in several small hydraulic faces and in one underground mine. In contrast to the aforementioned artificial outcrops, natural exposures of the "gravels" are rather sporadic, but because of the distinctive soil which tends to form from them, their contacts against all other formations except the Ione may be traced with reasonable accuracy.

Numerous references to the "auriferous gravels" of the Oroville area appear in the literature dealing with Sierran geology. Notable among these are papers by Pettee (1880, pp. 479-486), Preston (1893, pp. 155-157), Diller (1894, pp. 417-418), Lindgren (1911, pp. 86-89), and Allen (1929, pp. 398-401). Lindgren (1911, pp. 86-87) presented a section measured at the Cherokee hydraulic mine:

The following is the section beginning from the bedrock:

> (*a*) Hard cemented greenstone gravel, 5 to 10 feet thick, part angular, very poor in gold. Some quartz cobbles. No gold on bedrock.
>
> (*b*) Local small streaks of black clay with wood and bark, covered in places by (*c*) small blocks of basaltic lava, probably a local intrusion.
>
> (*d*) Partly cemented, very coarse, fresh blue gravel, 20 to 30 feet thick, with large blocks of greenstone, partly rounded. Spaces between filled with a little sand and well-washed quartz and greenstone. Surface almost level . . . .
>
> (*e*) Few feet of rotten bowlders, simply the decomposed gravels of *d*, acting as bedrock for stream depositing fine gravel.
>
> (*f*) White sand and quartzose gravel, 50 feet thick, mostly very fine, some a little coarser, cobbles on bedrock of *e*. Lower part yields 25 cents to the cubic yard in fine gold. Fluviatile stratification very distinct.
>
> (*g*) Yellowish white sandy clay, 200 feet thick, nearly without structure; in places with horizontal beds.
>
> (*h*) Massive basalt, 50 to 75 feet thick.

Lindgren's units (a), (d), and (e) have been discussed already in the present paper. Allen (1929, pp. 398-401) commented on the section described by Lindgren and, on the basis of lithology and stratigraphic relations, considered that Lindgren's unit (g), "yellowish white sandy clay", "probably belongs to the Rhyolitic tuff [i.e. Valley Springs] period".

The most characteristic lithologic types which make up the "auriferous gravels" are light-colored, loosely consolidated, quartzose sandstone and conglomerate, and varicolored, massive siltstone and claystone. Minor beds of carbonaceous shale are also present in certain parts of the section. The sandstone and conglomerate are intimately interbedded and frequently grade into one another. These coarser-grained sediments are most often white, light gray or light buff, upon which may be superimposed streaks of orange or yellow iron oxide. At one point in the Cherokee mine, quartz sandstone in the lower part of the section exhibits a peculiar lavender tint, apparently imparted by minor quantities of ferruginous matter. Individual strata may be thick-bedded or thin-bedded. Often where thin bedding occurs, cross-bedding is excellently developed. Channeled breaks between two units are common. Most of the sandstone contains scattered pebbles and often grades through increasingly pebbly portions into conglomerate. The conglomerate itself invariably contains a prominent matrix of sand like that with which it is intercalated.

Both the sandstone and the conglomerate are typically quite friable. But in many artificial excavations, such as the several hydraulic mines of the area, these loosely consolidated sediments may support steep, nearly vertical faces for a considerable length of time. The weak consolidation may be attributed mainly to the abundance of finer-grained matrix material rather than to the presence of any introduced cementing agent. Locally, certain thin beds are hard and well-cemented by dark red or reddish-brown iron oxide. Under the microscope, irregular patches of siderite are seen to accompany the oxide and appear to have been replaced by the latter. It is possible that siderite was the only original cementing agent and that most of it has been replaced by iron oxide.

Grain-size in the sandstone varies from fine to coarse; medium- or coarse-grained types are most common. Individual sandstone beds usually exhibit fair size-sorting if grains alone are considered, but because the sandstone almost always contains significant amounts of silt or clay, or both, as matrix material, the overall aspect is one of poor size-sorting. Also noteworthy is the predominance of angular grains.

By far the most abundant mineral present as grains in the sandstone is quartz. Pearly white or cream-

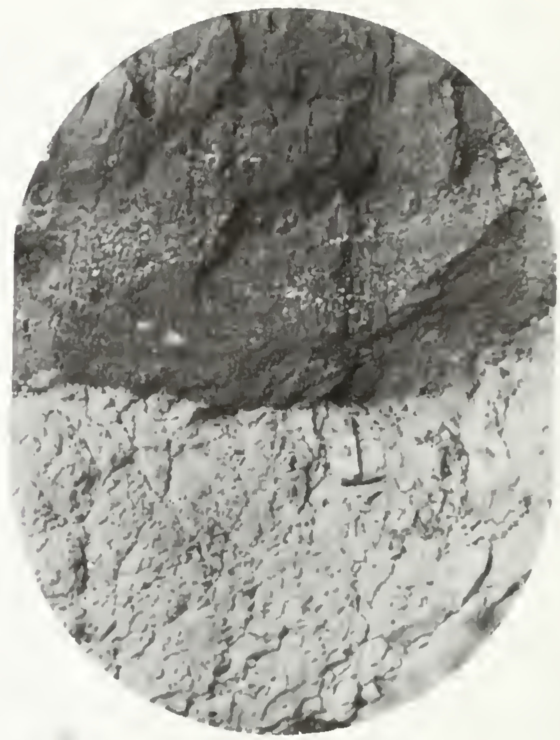


Figure 27. Plastic claystone interbedded with sandstone and conglomerate. "Auriferous gravels", Cherokee mine.

colored plates of kaolinite are characteristically present in small amounts in the lower part of the "auriferous gravels", while biotite is the only micaceous mineral of any importance in the upper part of the section. Feldspar is rare or absent in the lower part of the formation but is characterisrically present in small quantity in the upper part. Bedding in the sandstone may be manifesred by slight variations in grain-size, by the presence of thin lenses of claystone or of pebble-conglomerate, or by the occurrence of thin laminae rich in mica.

The conglomerate is made up largely of subrounded to well-rounded pebbles and cobbles of hard siliceous materials—principally white quartz and both light- and dark-colored chert. The clasts range in maximum dimension from a few millimeters to 5 or 6 inches, but the average size in any single stratum of conglomerate rarely exceeds one inch. Almost without exception, the clasts are loosely packed and are set in a matrix of light-colored quartz sand like that described above. White quartz usually constitutes at least 50 percent of the pebbles and cobbles, and in many instances reaches 80 or 90 percenr. Chert may make up 10 to 50 percent of the clasts. Pebbles of firm white or yellow claystone commonly accompany these more resistant types, and locally may constitute 20 percent of the pebbles. Many of the chert pebbles are of a peculiar reticulated type not found in the nearby bedrock terrane.

There is close megascopic and microscopic similarity between the sandstone of the "auriferous gravels" and that of the Ione. The sandstone in the lower part of the "auriferous gravels" is highly argillaceous, and the fine- to medium-grained varieties may contain up to 40 percent of clay. Abundant quartz occurs in angular, often "splintery" grains, accompanied by subordinate amounts of detrital chert and feldspar. Plates of kaolinite may constitute as much as 5 percent of the rock. Among the heavy minerals, which make up from 1 to 4 percent of the sediment, the dominant nonopaque minerals are epidote, zircon, and clinozoisite. In one sample from about 150 feet above the base of the formation at Cherokee, a single euhedral diamond was found. The lowest sandstone at Morris Ravine and at Cherokee carry little else besides opaque minerals and euhedral zircon in the heavy mineral fraction. As in the Ione, the sandstone in the upper half of the "auriferous gravels" contains abundant biotite and little or no kaolinite. Quartz is the most abundant constituent, but feldspar is more abundant than in the lower part of the section.

Variegated claystone and siltstone are abundant in the "auriferous gravels". Many of them are markedly similar to those found in the Ione Formation. Much of the upper part of the section consists of pelitic types, and thin, lenticular strata of claystone or siltstone are commonly intercalated with the coarser-grained sediments in the lower half of the gravels (Fig. 27). The colors most often observed in the pelitic sediments are white, light gray, and yellow. Mottled color-combinations, such as brick-red and blue-gray, brown and gray, or red and cream-white, also occur frequently. Most of the claystone is massive and quite compact and, when dry, breaks into blocky fragments. Fissility is seldom developed. The amount and nature of admixed impurities in the claystone are variable; some of the claystone is quite evenly textured and pure, while some contains noteworthy amounts of silt, angular quartz sand-grains, or rounded quartz pebbles. At a few localities, concretions of iron oxide are abundant along certain horizons.

Figure 28. Terraced lithomarge surface overlain by hard, flaggy "iron crust". Two terrace levels are visible. South end of Cherokee hydraulic mine.

Much of the claystone is markedly similar in appearance to the residual claystone or lithomarge upon which the "gravels" frequently rest. Undoubtedly some, and perhaps most, of it represents material reworked directly from the residual clays. Where detrital claystone lies at the base of the section it is easily mistaken for residual clay, and may be distinguished only by its content of scattered angular sand-grains. An interesting type of detrital claystone occurs at several localities on the northwest edge of the Cherokee channel. It is pebbly and has a crude, subparallel fissility. Close examination shows that the fissility is due to the presence of slabs of bedrock which have been converted to clay and in which an original slaty cleavage is still recognizable.

At many localities, the "auriferous gravels" rest directly upon, and have preserved, a deeply decayed bedrock surface. Without doubt, the alteration of the bedrock can be attributed to the pre-Ione period of deep chemical weathering or partial laterization which Allen (1929, pp. 383-394) postulated to account for similar features seen in other parts of the Sierra. The general effect of the pre-Ione weathering in the Oroville quadrangle has been the production of a variegated clay or clay-like rock which presumably represents that part of the lateritic profile known as lithomarge. At a few places, true laterite may be present. One such occurrence is in the head of Sawmill Ravine, near Campbell Flat, where a small clearing is underlain by dark red pisolitic clay. On the other hand, transitional stages between lithomarge and fresh bedrock are frequently found. The lithomarge varies widely in color, but is usually white or some shade of yellow or red. Mottled combinations of various colors are common. In most examples of the lithomarge all traces of original structure have been obliterated, but at a few localities relict cleavage or bedding is plainly visible.

The surface of the lithomarge at Cherokee is often capped by a hard, flaggy reddish-brown crust of iron-oxide (Fig. 28). The crust may have a thickness of several inches. It usually contains scattered angular grains of quartz and in some places cements the lowest part of an overlying conglomerate or sandstone. The "iron crust" may be related to the process of laterization, or may have been formed by precipitation of the necessary materials after the lithomarge had developed and been buried by later sediments. Similar crusts are found on various strata of the "auriferous gravels", and it is possible that not all of the "iron crusts" are of an identical origin.

An interesting example of the crust occurs in the southern part of Sawmill Ravine. There, a series of small terraces or benches, cut in both residual and reworked lithomarge, has been exposed by hydraulicking and natural erosion. The fronts of the terraces trend slightly east of north and slope toward the west as much as 60 degrees. They have presumably been cut by stream- or wave-action. The terraced surface is coated with "iron crust" which in turn is partly buried by sediments of the "auriferous gravels" (Figs. 29, 30). Similar crusts are "perched" in the overlying sediments.

The maximum exposed thickness of the "auriferous gravels" in the Oroville quadrangle is approximately 350 feet. The formation is in onlap contact with a west-sloping bedrock surface so that its thickness rapidly diminishes toward the northeast. For example, the

Figure 29. Terraced lithomarge surface overlain by "iron crust". View northwest. South end of Cherokee hydraulic mine.

Figure 30. Terraced lithomarge surface overlain by "iron crust". South end of Cherokee hydraulic mine. Two terrace levels are visible. View is to southwest.

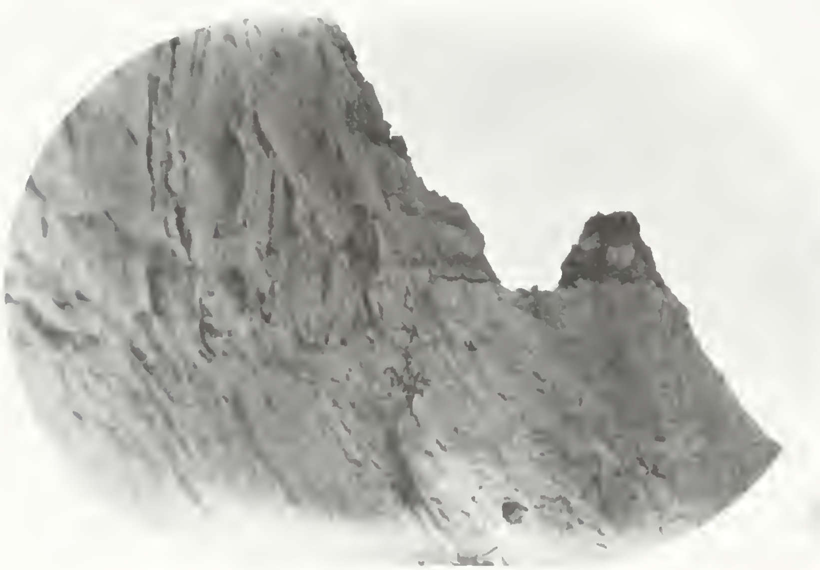


Figure 31. Disconformity between claystone and overlying sandstone. "Auriferous gravels." West face of Cherokee hydraulic mine, view north.

Figure 32. "Auriferous gravels" in abutment contact with bedrock (lithomarge). Cherokee hydraulic mine.

thickness of the formation in Morris Ravine is approximately 350 feet, but within a mile to the northeast little or no "gravel" occurs. A small part of the marked thinning is due to the slight angular discordance which exists between the "auriferous gravels" and the overlying "older basalt", but most of it can be attributed to the slope of the bedrock surface.

A stratigraphic section of the "auriferous gravels" and related units at the Cherokee hydraulic mine was measured by Messers. O. E. Bowen and Mort D. Turner of the California Division of Mines, and the writer. The section was measured on the west face of the mine, and was supplemented by observations made in other parts of the mine. The results are presented in the appendix.

At least three well-defined stratigraphic breaks occur within the "auriferous gravels" section at the Cherokee mine. Similar discontinuities probably occur in the section at Morris Ravine, but were not observed because of the poor exposures there. All of these breaks are marked by laterally consistent undulating sheets of "iron crust", similar to those described above. They are not restricted to individual beds but transect true bedding and appear to lie on irregular, channeled surfaces (Fig. 31). The "iron crusts" occur at breaks between sediments of different porosity and permeability, such as an interface between sandstone and claystone. In almost all cases, the less permeable material lies below the crust. Presumably the "iron crusts" consist in large part of iron oxide that has been carried in waters which percolated through a permeable medium and was precipitated at or near the interface with a material of lower permeability.

At one point in the Cherokee hydraulic mine, the uppermost claystone of the "auriferous gravels" is overlain by about 15 feet of pale buff thin-bedded, cross-bedded quartz sandstone (see unit 14, measured section). Unlike the sandstone of the underlying section, this sandstone is quite well sorted and free of argillaceous matrix material. It may represent the accumulation of grains reworked and washed free of clay from some of the underlying auriferous gravels. Because of the very limited extent of this unit, it was not mapped separately or assigned a formational name. Thin partings of dark gray clay-shale near the base of the sandstone contain abundant fossil leaves of probably Eocene age.

Several writers have stated their belief that the Sierran "auriferous gravels" or a part thereof are equivalent to the Ione Formation (Lindgren, 1894, p. 3; Turner, 1894a, p. 4; Lindgren, 1911, p. 24; Dickerson, 1916, pp. 417-418; Allen, 1929, pp. 395-402). Allen (1929, p. 402) showed conclusively that the "mineral composition of the white quartz gravels [of the "auriferous gravels"] is similar to the Ione, and the gravels were deposited by the same streams which laid down the delta deposits of the Ione". The present writer is in agreement with such a correlation insofar as the Oroville area is concerned. In the Oroville quadrangle, the "auriferous gravels" and the Ione occupy an identical stratigraphic position, are laterally continuous, and contain, in part, mutually identical lithologic types. The contact between the two units as shown on the geologic map is vague and arbitrary and represents at best the mean position of a very gradual change from the generally coarser-grained sediments of the "auriferous gravels" into the dominantly finer-grained sediments of the Ione. The writer found no evidence in support of Allen's suggestion (1929, p. 401) that part of the strata above the "quartz gravels" at Cherokee "might be an altered tuff" and "probably belongs to the Rhyolitic tuff period". The occurrence of fossil leaves, almost certainly of Eocene age, in beds at the top of the section (see p. 162) would rule out a correlation with at least the main part of the Sierran rhyolite tuffs, which appear to be Miocene in age (Gale, *et al.*, 1939, pp. 79-80).

The youngest rocks lying beneath the "Auriferous gravels" belong to the "greenstone gravel" in the northern part of the Cherokee hydraulic mine and the "Dry Creek" (?) in the southern part of the mine. But because of the irregularity of the underlying bedrock surface, both of these units are rather limited in distribution and neither occurs over a wide area. The contact between "Dry Creek" (?) beds and "auriferous gravels" was directly observed at only one locality and appears to be sharp but conformable. The contact between the "greenstone gravel" and the "auriferous gravels", as mentioned above, is apparently a slight disconformity. At many places the "gravels" rest directly upon bedrock, and the contact is a profound angular unconformity. In detail the bedrock surface is quite irregular, but in broad aspect it slopes gradually westward, and in several places the beds of the "auriferous gravels" abut sharply against this surface (Fig. 32).

Except in the south part of Morris Ravine, the "auriferous gravels" are overlain with slight angular unconformity by the "older basalt", which forms the broad, flat-topped eminence of Table Mountain. The contact is essentially planar and dips a few degrees toward the west-southwest. The relation between the two formations is best seen at the Cherokee hydraulic mine. Several units at the top of the "gravels" section, present on the west side of the mine, are missing on the east side of the mine, so that the "gravels" appear to be gradually overlapped toward the east. Near Monte de Oro and on the east side of South Table Mountain a relatively thin sequence of interbedded andesitic mudflow, volcanic sandstone and conglomerate, belonging to the Mehrten (?) Formation, is present between the underlying "auriferous gravels" and the overlying "older basalt". The contact is not well-exposed, but to the west the Mehrten (?) shows a markedly disconformable relationship with the Ione Formation (essentially equivalent to the "auriferous gravels").

The earliest sediments of the "auriferous gravels" represent fluviatile deposition in stream channels which may have existed for a considerable length of time. At Cherokee, the "auriferous gravels" initially accumulated in the same channel in which the "greenstone gravel" had been previously deposited. Also at this time, one or more channels were filled at the present site of Morris Ravine. To the southwest, contemporaneous deltaic sediments accumulated at the mouth of the various streams, forming the deposits of the Ione Formation. As sedimentation progressed, successively younger sediments were spread out on a broadening flood plain, and the identity of the original channels was gradually lost.

Fossil leaves were collected by the writer at two localities in the Cherokee hydraulic mine. The localities are fully described in the appendix. The older of the two assemblages (Locality 12) occurs in shales near the base of the "auriferous gravels" section, while the younger (Locality 13) is found in the unnamed beds at the top of the section. The leaves were identified by Professor R. W. Chaney who has furnished the following statement * regarding them.

> The leaves from the lower horizon [Locality 12] are somewhat fragmentary, but the following forms may be recognized:
>
> *Phytocrene sordida* (Lesquereux)
> *Rhus mixta* Lesquereux
> *Cinnamomum dilleri* (?) Knowlton
> *Calyptranthes arbutifolia* (?) Chaney and Sanborn
> *Nectandra presanguinea* Chaney and Sanborn
> *Cornus kelloggii* Lesquereux
> *Meliosma goshenensis* (?) Chaney and Sanborn
> *Viburnum* cf. *variabilis* MacGinitie
> *Symplocos oregona* Chaney and Sanborn
> *Persea pseudocarolinensis* Lesquereux
> *Juglans* sp. (probably an Eocene species)
>
> The assemblage is definitely of the Chalk Bluffs type, and is no older than middle to upper Eocene. The plants grew in a warm temperate or subtropical climate.
>
> The leaves from the upper horizon [Locality 13] are quite fragmentary. The following forms may be recognized:
>
> *Persea pseudocarolinensis* Lesquereux
> *Nectandra presanguinea* Chaney and Sanborn
> *Tetracera castaneaefolia* MacGinitie
> *Ficus* sp. (possibly cf. *goshenensis* or *quisumbingi*)
> *Cupania* sp. (possibly *oregona*)
>
> The floralistic aspects of this assemblage suggests that it is middle to upper Eocene. The plants represented grew in a warm temperate or subtropical climate.

Regarding the age of the Chalk Bluffs flora based purely on a consideration of the flora itself, MacGinitie (1941, p. 92) stated:

> The Chalk Bluffs flora is . . . older than the middle part of the Upper Eocene, and the evidence indicates that it is older than the Claiborne flora [middle Eocene, Gulf Coast].
>
> There is thus nothing in the relationships of the flora to contradict the assignment of the Ione formation [MacGinitie considered that the plant bearing beds at Chalk Bluffs represent a continental facies of the Ione formation] to the Capay stage of the Middle Eocene, and much to substantiate this age determination.

#### Mehrten (?) Formation

Outcrops of Tertiary andesitic tuff, lapilli tuff, and tuff-breccia, with associated volcanic sandstone and minor conglomerate, are scattered over the southeastern part of the Oroville quadrangle. These rocks undoubtedly belong to the "Sierran andesite series" of the older literature and, as such, represent an outlier at the northwest corner of the regional outcrop area of this unit. They have many features in common with the upper Pliocene Tuscan Formation mapped in the northern part of the area, but the two are nonetheless quite distinct. The andesitic rocks are tentatively referred to the Mehrten Formation, which is better known in other Sierran areas to the south and east.

Although the presence of vast quantities * of Tertiary andesitic rock in the Sierra Nevada has long been recognized (Whitney, 1865; Turner, 1894, p. 487), no formal names were generally applied to these deposits until 1938. Clark and Anderson, in 1938, cited evidence southeast of Marysville which indicated that not all of the "Sierran andesitic series" belongs to the commonly stated age of late Miocene to early Pliocene, but that certain of the andesites were erupted much earlier. They (pp. 937-938) used the name "Reeds Creek andesitic rocks" for strata which they suggested might be of middle Eocene to possibly late Eocene or early Oligocene age. Gale, *et al* (1939, pp. 61-71), working in the Mokelumne River area, proposed the name Mehrten Formation for the Tertiary andesitic rocks there, and the term has since been widely used for correlative deposits in other Sierran areas (cf. Taliaferro and Solari; Curtis, 1954).

Thus the term "Mehrten Formation" is applied only provisionally to the rocks under discussion. First, they are geographically remote from any outcrops known to be Mehrten. Second, and perhaps more important, the name Mehrten is used with the realization that these rocks may instead be equivalent to andesites

* Personal communication, 1954.

* Curtis (1954, p. 453) estimated that the Mehrten once covered an area probably in excess of 12,000 square miles.

believed to be much older than the Mehrten, such as the "Reeds Creek andesitic rocks" of the Wheatland region. (Clark and Anderson, 1938, pp. 940-941).

Outcrops of the Mehrten (?) Formation are rather limited in the area of study, owing to widespread burial by later sedimentary and volcanic deposits and to later erosion. The exposures occur in five rather widely separated areas in the southeast quarter of the Oroville quadrangle. The largest area underlain by the Mehrten (?) includes poorly exposed outcrops beneath the "older basalt" on South Table Mountain and in the Campbell Hills. Smaller areas of outcrop lie, respectively, on Monte de Oro, on the west bank of the Feather River near Thermalito, just east of the river and north of Oroville, and about 2 miles due east of Oroville near the road to Forbestown.

The most abundant and characteristic rock types found in the Mehrten (?) Formation in the area of study are andesitic lapilli tuff and tuff-breccia. These rock-types occur in all sections of the Mehrten (?) except that on Monte de Oro, and the outcrops which lie due east of Oroville are dominated by them. They are generally somewhat light-colored, varying from shades of light gray or tan to medium brownish-gray. Internal stratification is usually lacking, although these pyroclastics are frequently intercalated with sedimentary rocks. Blocks and lapilli are firmly held in a hard, compact matrix which contains noteworthy amounts of silty and clayey material and many sand-sized crystal, lithic and vitric fragments. The blocks and lapilli are typically subangular; their average size varies from place to place, but generally lies between 1½ and 3 inches. In any one stratum, the sorting with respect to size of fragments is generally poor. Blocks 6 inches across are common, but no blocks larger than 10 inches were observed. None of the lapilli tuff or tuff-breccia examined by the writer is monolithologic with respect to composition of the contained lapilli or blocks. Furthermore, the lapilli are characterized by somewhat different assemblages of rocks than are the blocks, and several types found among the lapilli do not occur as blocks. The great majority of the blocks are one of several types of generally nonvesicular or microvesicular porphyritic andesite. Almost all of these contain prominent phenocrystic hornblende, augite, hypersthene, or biotite, or combinations of these minerals. The phenocrysts are set in an aphanitic or microcrystalline groundmass, the usual color of which varies from light gray to dark gray. Some of the andesites, however, have been more or less altered to shades of brown or reddish brown. The associated lapilli are largely subangular to subrounded fragments of the same lithologic types found among the blocks, with a lesser number of fragments of black to red scoriaceous basalt and scattered bits of light-colored pumice and brown claystone. The sand-sized material of the matrix includes fragments or euhedra of feldspar, hornblende, pyroxene, and biotite, lithic fragments of variously colored dense volcanic rock and bits of devitrified pumiceous glass.

Microscopically, almost all of the blocks and lapilli are seen to be of andesite. Phenocrysts constitute from 10 to 90 percent of the rock. The groundmass may be holocrystalline, hypocrystalline, or holohyaline. The hypocrystalline types are often trachytic, with a swarm of microlitic feldspar set in a base of pale brown glass. Others have a groundmass of opaque black glass. The majority of the phenocrysts are of zoned plagioclase ($An_{35}$-$An_{79}$) which is often strongly altered. The most abundant ferromagnesian mineral is green hornblende, which is almost invariably fringed with granular magnetite. Less commonly, the amphibole is oxyhornblende. The hornblende may occur alone, but more often is accompanied by biotite or hypersthene. Types bearing only hypersthene or augite, or the two together without hornblende, are less abundant. Fragments of non-porphyritic, devitrified glassy scoria and woody pumice are common among the smaller lapilli. The matrix is a dirty tan, semi-opaque, microcrystalline aggregate of nearly isotropic minerals with abundant sand-sized euhedra and broken crystals of plagioclase and ferromagnesian minerals, accompanied by lithic and vitric fragments.

Interbedded with, and subordinate to, the coarser pyroclastic rocks of the Mehrten (?) is light-colored lithic-crystal tuff. Typical colors are pale yellowish-white, light purplish-tan, light gray or brownish-gray. It tends to be massive, firm and compact, and to break with a blocky fracture. Abundant small fragments of dark aphanitic or microcrystalline volcanic rocks are accompanied by scattered euhedral or fragmented crystals of feldspar, hornblende, pyroxene, and biotite. These sand-sized fragments are contained in a firm matrix of clay and silt.

Another important lithologic type in the Mehrten (?) Formation is pale buff to bluish-gray volcanic sandstone. In many outcrops, this rock shows a marked similarity to the volcanic sandstone of the upper Pliocene Tuscan Formation, but may be distinguished from the latter by its close association with andesitic, rather than basaltic, tuff-breccia and by the presence in the sandstone at many localities of pebbles of andesite. The sandstone is thick- to thin-bedded; cross-bedding occurs locally. Much of it is soft and friable, but some is firm and compact, without an apparent cementing agent. It tends to be moderately well-sorted with respect to size, although the coarser-grained types are generally ill-sorted. Grain-size ranges from very fine to very coarse, and much of the sandstone contains appreciable amounts of admixed silt or clay or both. Some of the sandstone which occurs in the basal conglomerate on South Table Mountain has a prominent matrix of yellowish-green clay. Scattered granules and pebbles of andesite are often present, and thin, lenticular pebble beds are common. The grains are predominantly subangular, but vary from angular to subrounded. The most abundant constituents among the grains are fragments of black, gray, or red dense volcanic rocks. Feldspar is also prominent, and some of the sandstone, probably of tuffaceous character, contains abundant euhedra of feldspar. Flakes of biotite are commonly present and in certain beds are unusually abundant. Other ferromagnesian minerals, such as hornblende and hypersthene, and metallic grains, like magnetite, occasionally may be identified. Some quartz is present but does not appear to be an important constituent. Identification of the mineral grains is often hampered by a white or light-gray mineral substance which coats the grains.

Lenticular beds of friable volcanic granule to cobble conglomerate are sporadically interbedded with the pyroclastic rocks and volcanic sandstone of the Mehrten (?) Formation. These consist of subrounded to well-rounded pebbles, cobbles and occasional boulders of andesite, like that found as blocks in the tuff-breccia, with lesser amounts of quartz, chert, old basic to intermediate volcanic rocks, and plutonic rocks. The clasts are set in a matrix of light-colored, ill-sorted sand. The conglomerate tends to be poorly sorted with respect to size. Some beds consist entirely of granules and small pebbles, while others are dominated by 3- or 4-inch cobbles. The only conglomerate in the Mehrten having marked lateral consistency is that which occurs on the north and east flanks of South Table Mountain. There, from 25 to 40 feet of pebble to cobble conglomerate and interbedded yellowish-buff sandstone mark the base of the formation. This conglomerate contains abundant pebbles and cobbles of unaltered hornblende andesite, with many well-rounded clasts of white quartz and chert, and lesser quantities of schist, metavolcanic rock, quartzite, and granodiorite. The andesite is similar to types found as blocks in the overlying tuff-breccia and was apparently derived from older parts of the "andesitic series" which probably once lay to the east. The quartz and chert presumably represent material reworked from the "auriferous gravels", while the other clasts mentioned above all have counterparts in situ in the nearby Sierran bedrock terrane.

On South Table Mountain and in the Campbell Hills, the Mehrten (?) Formation is underlain disconformably by the Ione Formation on the west and by the "auriferous gravels" on the east. The disconformity is generally broad and gentle, but locally may be sharply defined. Such a relationship is seen in the Campbell Hills where about 100 feet of Ione strata are cut out within a quarter of a mile along strike. To the south and east, near Oroville and on Monte de Oro, the Mehrten (?) is seen to rest directly on bedrock where the base of the formation is exposed. A similar relationship probably exists east of Oroville where the lower portion of the Mehrten (?) is concealed beneath the Red Bluff Formation. The Mehrten (?) strata on Table Mountain and in the Campbell Hills are overlain by the "older basalt". A slight angular unconformity may separate the two units, but its existence has not been definitely established. The Mehrten (?) south of Table Mountain is overlain unconformably by the Red Bluff Formation, except locally where erosion remnants of an unnamed pumice tuff overlie the Mehrten. The greatest exposed thickness of the Mehrten (?) Formation lies on the north side of South Table Mountain and on the south flank of the Campbell Hills; a maximum of about 200 feet of andesitic strata is exposed. East of Oroville, near the road to Forbestown, a maximum thickness of 50 feet is exposed, and an undetermined thickness of the lower part of the formation lies buried beneath the Bed Bluff Formation. On the west bank of the Feather River near Thermalito, 21 feet of interbedded andesitic lapilli tuff, tuff, volcanic sandstone and conglomerate lie above the level of the river and disconformably beneath the Red Bluff.

The Mehrten Formation (restricted) is upper Miocene to lower Pliocene.* Louderback (1924, p. 19) concluded that the "period of great Tertiary andesitic eruptions of the Sierra Nevada is . . . Lower Pliocene, or Upper Miocene, perhaps bridging the gap between these two epochs." A similar conclusion was reached by Chaney, Condit, and Axelrod (1944) on the basis of studies of fossil floras and vertebrate remains. As shown by Clark and Anderson (1938), however, a portion of the Sierran andesites may be as old as middle Eocene and no younger than lower Oligocene. Thus some care must be exercised in the assignment of an age to andesitic rocks in the Sierra for which no direct evidence of age is at hand.

The andesitic tuff-breccias are believed to have been emplaced as volcanic mudflows which formed in connection with volcanic activity in the higher parts of the Sierra Nevada. The associated volcanic sedi-

* Since completion of this manuscript, new evidence bearing upon the age and correlation of the Mehrten (?) Formation of the Oroville area has accumulated.

Durrell (1959a) questioned the very presence of andesitic volcanic rocks beneath the "older basalt" at South Table Mountain. He (p. 209) concluded that "the basalt ["older basalt" of this paper] of Oroville Table Mountain rests on the Ione formation and on "Auriferous gravels", and there is no intervening andesite tuff, tuff-breccia, or mudflow breccia that can be correlated with any such unit elsewhere in the Sierra Nevada."

Dalrymple (1964), studying the section at South Table Mountain in connection with a potassium-argon dating project, found (p. 14) "andesite mudflow breccia that is indistinguishable from the andesite mudflow breccias of the Mehrten Formation" beneath "older basalt". Dalrymple flatly rejects Durrell's conclusion, quoted above, as "incorrect". The present writer agrees with Dalrymple.

Dalrymple (p. 14) obtained a potassium-argon date of 23.8 million years on plagioclase from a three-inch bed of dacite tuff lying near the base of the andesitic rocks at South Table Mountain. This indicates that at least a part of the rocks here mapped as Mehrten (?) Formation are of early Miocene age (Arikareean in terms of standard North American land mammal ages). Dalrymple (p. 9-11) believes that the Mehrten Formation proper, farther south in the Sierra Nevada, ranges in age from middle Miocene through late Pliocene.

ments probably represent the accumulation of debris reworked by fluviatile action from the mudflows as the latter moved down over the somewhat rugged, but generally west-sloping, topography toward the site of the present Great Valley.

Mudflow origin appears to have been generally accepted for much, if not all, of the widespread Tertiary andesitic tuff-breccia lying in the Sierra Nevada. Early mention of such a possible origin was made by Turner (1896, pp. 537-539). Turner compared the Sierran andesites to the products of the "eruption" (or explosion) of Bandi-san in Japan in 1888 and of the eruption of Gunung Pepandajan in Java in 1772. He noted, however, that in both of the foreign examples, the material ejected "traveled but a few miles and down a comparatively steep grade", while the fragmental material of the Sierran andesites was transported from the source areas at the crest of the range "a distance of about 50 miles, on a comparatively gentle slope". Lindgren (1911, pp. 31-32) also believed the tuff-breccias to have been emplaced as volcanic mudflows.

The andesitic rocks at Oroville, while they are of rather limited exposure, offer nothing which would conflict with the assumption that they were emplaced as volcanic mudflows. On the other hand, there are several facts of their occurrance which appear to rule out any of the other commonly accepted modes of origin of volcanic breccias (cf. Anderson, 1933, pp. 245-252). The tuff-breccia of the Mehrten (?) consists dominantly of non-vitric material, although most of it contains very minor quantities of pumice. Markedly vesicular material among the blocks and lapilli is exceedingly rare; most of the fragments are quite dense and massive. Recognizable volcanic bombs do not occur. The breccia as a whole is without internal bedding, is markedly ill-sorted with respect to size of component fragments, and contains an abundance of fine-grained matrix material. The andesitic deposits at Oroville are at least 40 miles from any known eruptive centers from which the debris might have been originally ejected, and there is no reason to suppose that the slope over which the tuff-breccia was transported was ever steeper than 1 or 2 degrees, except locally. These features, taken together, suggest that the Mehrten (?) tuff-breccia does not owe its accumulation principally to volcanic processes involving violent explosive action or the production of avalanches. Nor is it clear in what way such material could have been transported for the long distances assumed without the aid of water combined with the finer-grained material to form a highly mobile, mud-like substance. It has been aptly pointed out by Curtis (1954, p. 456) that the "enormous explosive action" called forth by Lindgren (1897, p. 3) to explain the production of the fragmental andesites is irreconcilable with the imperceptible merging of tuff-breccias into intrusive bodies of massive andesite described by Lindgren in the Truckee area.

No volcanic conduits which might have supplied the andesitic material were found within the Oroville quadrangle by the present writer. Rather, the ultimate source of the andesite is believed to have been the volcanic centers noted by Turner (1894) and Lindgren (1897, 1911) far to the east of the area under discussion.

Until 1944, no adequate explanation had been advanced which might account for the initial brecciation of the andesitic material in the Sierra. Durrell (1944) described several breccia dikes near Blairsden, in Plumas County, from which at least part of the andesite mudflows in that area appear to have originated. Durrell (pp. 267-272) postulated the violent escape of the volatile constituents from a rapidly congealing magma to account for the brecciation seen in the dikes. The expulsion of volatiles was correlated with their increasing concentration and vapor pressure, due mainly to rapid crystallization as the magma rose and was chilled by contact with wet wall rocks. Curtis (1954) has criticized Durrell's thesis. He (pp. 461-462) examined extrusive and intrusive andesites near the crest of the range in Alpine County, and concluded that "the great mass of andesite in the Mehrten Formation was extruded from conduits now marked by domes, necks, and dikes" and found that "the great bulk of the igneous rocks is fragmental microvesicular andesite that gives no indication of having been erupted with violence". Curtis (pp. 465-471) advanced an explanation for the brecciation which involves the vesiculation, increase in viscosity, and eventual rupture of a partly crystallized magma due principally to lowering of external pressures as the magma rises through the conduit.

#### "Older Basalt"

Oroville Table Mountain forms a conspicuous landmark in central Butte County (Fig. 33). The mesa owes its topographic form to the presence of a nearly flat lying, highly resistant cap of black dense basaltic lava. The name "older basalt" was adopted for this rock by Turner (1894, pp. 490-491), who used the term in order to distinguish the lava from certain younger basalts of different lithologic character cropping out in the same general area. The present writer prefers to continue this nomenclature since the term is well established in geologic literature concerning the Sierra.

The earliest description, of any note, of the "older basalt" at Oroville Table Mountain was that written by Pettee (1880) in conjunction with his studies of the auriferous gravels of the Sierra Nevada. Brief discussions of the "older basalt" were presented by Turner (1894, pp. 490-491; 1896). In the later paper, he noted (p. 543) that although the basalt is "older than the hornblende-pyroxene andesite [cf. Mehrten] . . . it is quite certain that some andesitic eruptions took place before the older basalt flows, since pebbles [of andesite] occur under the Oroville Table Mountain basalt."

Figure 33. South slope of South Table Mountain, showing cap of "older basalt" above Tertiary sedimentary and volcanic rocks. Thompson Flat in foreground. View north.

Turner observed that at two localities, one near South Table Mountain and other southwest of Wicks Corner, "dike-like masses of the basalt appeared to cut the Ione beds". The first of these was sought for but not found by the present writer. The second appears to be merely a large block broken loose from a part of the flow and emplaced in its present position largely with the aid of gravity, either by rolling or sliding, or both. The distribution of the lava at Oroville Table Mountain was shown by Lindgren in his reconnaissance map of the area (1911, Pl. 15, p. 86).

Outcrops of the "older basalt" cover approximately 12 square miles in the Oroville quadrangle. The lava is exposed on North and South Table Mountains (Fig. 34) as a relatively thin, undeformed plate dipping gently west-southwest (1°-2°). Outcrops of the basalt on the Campbell Hills and on the hills south and west of Wicks Corner represent erosion remnants and were apparently once connected to the main body of the flow on Table Mountain. A small disconnected part of the basalt underlies Sugarloaf, near Cherokee (Fig. 35). The "older basalt" occurs at many localities east of the present area (Turner, 1894, 1896, 1897, 1898), the most distant of which is the basalt at Red Clover Valley in Plumas County (approximately 60 miles east-northeast of Table Mountain). West of the Campbell Hills and the hills near Wicks, the "older basalt" is not exposed at the surface, and the flow passes beneath the Quaternary sediments of the Sacramento Valley. The basalt encountered in many of the gas wells and dry holes drilled in the Valley north of Sutter Buttes occupies the same stratigraphic position as the "older basalt" on Table Mountain (cf. Cross, *et al*, 1954), and it is almost certain that the two are equivalent. The basalt beneath the Tuscan Formation on Chico Creek, just beyond the northwest corner of the Oroville quadrangle, is identical, in hand specimens, to the lava on Table Mountain and is no doubt referable to the "older basalt". It is possible that the basalt flow (?) which directly underlies the Tehama Formation near Orland (Anderson and Russell, 1939, pp. 236-237) is also essentially the same age as the "older basalt", but

Figure 34. "Older basalt" on west side of North Table Mountain, near head of Flag Canyon. View east.

it is considered unlikely that the two units were erupted from the same volcanic conduit.

The "older basalt" is typically a black, hard, microcrystalline to extremely fine-grained, more or less equigranular olivine basalt. In most localities it is very sparingly vesicular, but vesicles may be locally abundant (to 30%). The vesicles may be spheroidal or drawn out and flattened. Amygdules of calcite or chlorophaeite are sporadically encountered. In hand specimens, the basalt typically appears nonporphyritic; usually the only primary mineral distinguishable with the hand lens is feldspar, present in abundance as microlites. Phenocrystic laths of plagioclase, up to 3 or 4 mm in length, are rarely visible.

As seen in thin section, typical specimens of the "older basalt" are slightly porphyritic, with scattered phenocrysts of plagioclase ($An_{43}$-$An_{67}$), and sometimes of augite, set in a hypocrystalline groundmass of variable character. In some specimens, the groundmass carries abundant microlites of plagioclase and is felty to trachytic, with intergranular augite, olivine, and magnetite and some intersertal black or green basaltic glass. Where phenocrysts of augite occur, a subophitic texture may be developed. In other specimens, a base of opaque black glass constitutes as much as 50 percent of the rock, and the texture is then intersertal to hyaloophitic.

A chemical analysis of the "older basalt" from Oroville Table Mountain was published by Turner (1894, p. 491). It is presented with the normative composition in Table 5.

Just beneath the "older basalt" at several localities are 15 to 20 feet of volcanic conglomerate. The pebbles and cobbles are subangular to subrounded and are loosely held in a prominent to predominant matrix of buff to yellow, friable, ill-sorted, biotitic, lithic sand. Over 90 percent of the clasts consist of black, dense basalt, which, except for its abundance of vesicles, is quite similar to the overlying "older basalt". Up to 10 percent of the pebbles are of older igneous, sedimentary, and metamorphic rocks, similar to types found in the Sierran bedrock. The basaltic conglomerate is thought to represent fluviatile deposition of detritus derived from flows of the "older basalt" erupted in other areas before the emplacement of the lava now found on Table Mountain.

The upper part of the "older basalt" is a massive, columnar-jointed lava. The individual columns are rather crudely developed, and rarely are over 5 or 6 inches in diameter. The lower part of the basalt is seldom directly observable due to the presence of a thick accumulation of talus from the upper part. In several places where it is not covered, however, such as at the Cherokee mine (Fig. 21) and on the southeast corner of South Table Mountain, the lower part of the lava is seen to consist of non-columnar basalt which has broken into angular blocks averaging several inches across. At the Cherokee mine, the lower half of the lava is a loose rubble of angular fragments. At South Table Mountain, the lower part is also fragmented, but the individual blocks have not been dislocated and fit together in jigsaw fashion, suggesting that the brecciation is due to cooling-shrinkage rather than to differential movement in lava of varying viscosity. The fragmental phase of the lava may be present at most other localities, but unless it were undisturbed and the individual blocks had not separated, the blocky rubble derived therefrom would be indistinguishable from the talus derived from the columnar phase. On the north side of South Table Mountain, at

Figure 35. "Older basalt" overlying "auriferous gravels" at Sugarloaf, Cherokee mine. View south.

*Table 5. Chemical analysis and normative composition of "older basalt" from Oroville Table Mountain.*
(Turner, 1894, p. 491; Washington, 1903, pp. 320-321)

| Analysis * | | Normative composition | |
|---|---|---|---|
| $SiO_2$ | 50.66 | or | 11.7 |
| $Al_2O_3$ | 13.97 | ab | 27.8 |
| $Fe_2O_3$ | 2.55 | an | 17.5 |
| FeO | 10.20 | di | 14.0 |
| MgO | 4.45 | hy | 17.9 |
| CaO | 8.08 | mt | 3.7 |
| $Na_2O$ | 3.32 | il | 4.6 |
| $K_2O$ | 1.95 | ap | 2.2 |
| $H_2O+$ | 0.43 | | |
| $H_2O-$ | 0.27 | | |
| $CO_2$ | none | | |
| $TiO_2$ | 2.39 | | |
| $P_2O_5$ | 1.01 | | |
| MnO | 0.29 | | |
| BaO | 0.22 | | |
| Cl | 0.02 | | |
| NiO | tr | | |
| SrO | tr | | |
| $Li_2O$ | tr | | |
| Total | 99.81 | | |

* Analyst: W. F. Hillebrand.

the head of the main northwest-flowing tributary to Schirmer Ravine, the lowest part of the "older basalt" is highly vesicular and exhibits well-defined horizontal platy jointing. The base of the lava is also exposed on the northeast end of the Campbell Hills, where it is columnar-jointed like the upper part of the lava on Table Mountain. The two types of lava, columnar above and non-columnar, brecciated below, may represent two different flows or may be separate parts of a single flow. Turner (1896, p. 567), writing on the "older basalt" of the Bidwell Bar quadrangle, noted that the "entire thickness of the basalt" north of the south fork of the Feather River is "not less than 500 feet" and found that there is "a series of benches" which "present the appearance of successive flows".

The "older basalt" on Table Mountain and on certain of the outlying exposures exhibits two well-marked systems of vertical joints which meet at more or less right angles. These joints are manifested both by topographic relief and by differences in vegetation. The joints appear as longitudinal depressed areas which give way to steep-sided, notch-like gullies at the edges of the flow. Between the joints bare lava is exposed, but along the joints a thin cover of soil has developed and grasses have taken root. The better developed of the two joint-systems is made up of long, broadly curving, convergent joints which trend approximately south at the north end of North Table Mountain and swing gradually around to the south-southwest farther south. The second joint-system consists of short, concentrically arranged joints trending transverse to the first joint-system. The two joint-systems show up well on aerial photographs of the area (Figs. 24, 36). Neither bears any consistent directional relationship to structures in the adjacent bedrock terrane or in the underlying Tertiary strata. It is assumed, therefore, that the jointing is an original structure developed in the lava at the time it was emplaced. It may be that the joints owe their formation to internal shear and tensional forces which were set up as the result of differential consolidation in a moving sheet of lava.

Erosion of the "older basalt" involves principally the processes of mass-wasting—rockslide, rockfall, and slumping—while stream-erosion plays an important, but indirect, role. This phenomenon is best seen on the west and south sides of North Table Mountain and on all sides of South Table Mountain. At these places, the basalt rests directly on a relatively thick sequence of barely consolidated Tertiary sediments. The edge of the basalt is a steep, in places vertical, cliff. As the soft understratum is removed by the action of running water and of gravity (slumping, etc.), support is removed from the edges of the lava, which is thus literally undermined. Because of the jointing in the basalt, the outermost parts are, on the whole, not held firmly to the rest of the flow. Thus, in time, large masses of blocky debris move away from the edge of the flow as rockslides or as rockfalls. In the case of the lava showing columnar jointing, such as characterizes all of the upper half of the basalt, individual columns may cling together in thick bundles and the whole may separate and eventually topple to some lower point, often without disaggregating to any appreciable degree (Fig. 21). Thus masses of columnar lava, as long as 50 feet, have been found at distances in excess of one-half mile from their supposed point of origin. An interesting case of slumping occurs at the south edge of North Table Mountain, just west of Coon Hollow. There, a segment of the flow fully 1200 feet long and 400 wide has slumped, with but slight tilting, several hundred feet down the slope. Stream-erosion plays a major role in removing the underlying sediments and the more finely broken

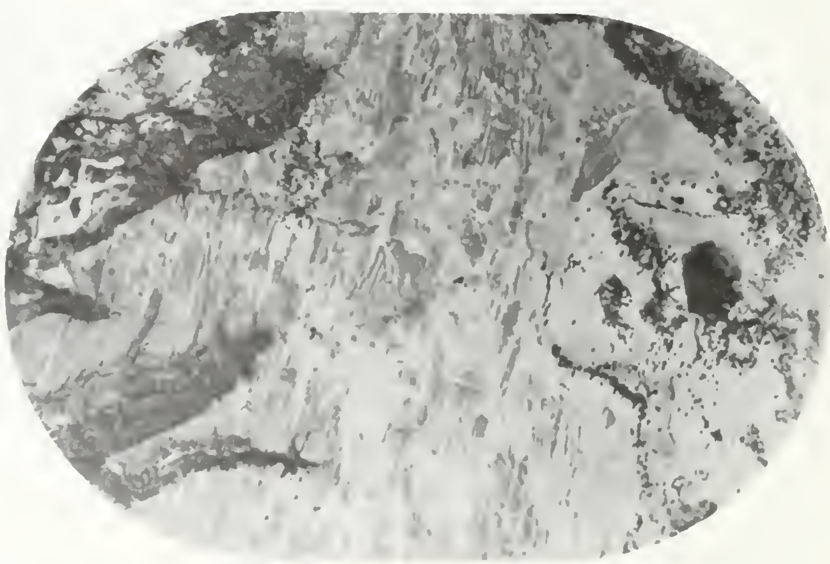


Figure 36. Aerial photograph showing north part of North Table Mountain. Joint pattern is in "older basalt". *Photo by U.S. Department of Agriculture.*

debris of the rockslides and rockfalls. Intermittent streams, such as Beatson Hollow, have worn small valleys across the top of the basalt on Table Mountain, but their effect is thought to be relatively small when compared to the mass-wasting at the edges of the flow. The near-planar surface of the lava is still plainly distinguishable. At the east edge of North Table Mountain, bold cliffs such as those found on the west side do not occur. At most places, Sawmill Ravine being a notable exception, the soft Tertiary strata are thin or absent, and the lava rests essentially upon bedrock. The bedrock is nearly as hard as the lava, so that differential erosion with attendant mass-wasting, while it does occur here, is of much less relative importance than on the west side.

The upper surface of the "older basalt" on both North and South Table Mountains is, except for local irregularities, nearly planar, and dips slightly, with near-uniformity, toward the west-southwest. It is clear that the basalt has undergone little or no deformation, but has been gently tilted. As indicated above, erosion appears to have proceeded principally at the edges, rather than on the surface, of the basalt. Thus the present surface is believed to closely approximate, in broad aspect, the original surface of the lava, except that the surface area has been greatly reduced. This preservation is due in part to the highly resistant nature of the basalt, but it may be that the basalt was once covered by later deposits which have since been stripped away. For example, it is conceivable that the andesitic breccias which now mantle the basalt at many localities to the east (Turner, 1897, 1898) might once have extended much farther to the west and covered the "older basalt" on Table Mountain.

The "older basalt" in most of the area rests, with slight angular unconformity, on several of the older Tertiary formations previously described. On the east side of North Table Mountain the lava overlies bedrock with marked angular unconformity. The youngest rocks directly underlying the basalt are the fragmental andesite and volcanic sediments of the Mehrten (?) Formation. The basalt overlaps the andesitic rocks to the east and north, and over most of North Table Mountain it rests on Eocene strata. A part of the overlap might be due to a slight angular discordance between the basalt and the Mehrten (?), but most of it is probably caused by the marked disconformity between the Mehrten (?) and the underlying Eocene strata. The thickness of the "older basalt", where it has not been affected by later erosion, is fairly uniform. It is thickest on South Table Mountain, where about 250 feet of lava are exposed. The average thickness in other places is 175 or 200 feet. This overall uniformity of thickness shown by the basalt indicates that the flow was poured out upon a rather even plain.

The "older basalt" overlies Tertiary fragmental andesite in the Oroville area, and is in turn overlain by fragmented andesite to the east (Turner, 1894, pp. 493-494). The age of the basalt therefore lies somewhere within the time of andesitic eruption in the Sierra. The latest evidence indicates that some, and perhaps most, of the andesites were erupted during the late Miocene and early Pliocene (Chaney, Condit and Axelrod, 1944). However, at least some of the Sierran andesites were emplaced no later than the early Oligocene (Clark and Anderson, 1938). Thus if the andesitic rocks at Oroville, questionably referred to the Mehrten Formation, actually belong to the later andesites, the "older basalt" may be upper Miocene to lower Pliocene. But if the andesites at Oroville are of the earlier period of eruption (cf. "Reeds Creek andesitic rocks" of Clark and Anderson), the lower age limit of the basalt must be extended at least as low as the early Oligocene.*

The writer was unable to locate any vent within the area from which the "older basalt" might have been extruded. The present regional distribution of the lava and the variation in thickness from one place to another suggest that the source may have been to the east. Turner (1896, pp. 614-615) noted that "it is probable that the older basalt issued at a number of vents, but the masses about Onion Valley Creek [in Plumas County, 35 miles east and north from Oroville Table Mountain] and the extensive sheets in the Bidwell area about Black Rock Creek, on the Mooreville ridge, etc., may perhaps have come from a single orifice near Onion Valley".

#### New Era Formation

The Tuscan Formation usually rests on a surface of low relief which has been developed on Eocene or older rocks. In several places, however, the Tuscan is underlain by coarse fluviatile sediments of post-Eocene age. These sediments contain debris derived largely from typical bedrock formations, and thus form a mappable unit, readily distinguished from the overlying Tuscan volcanic rocks and intercalated volcanic sediments.

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* Subsequent to the completion of this manuscript, several papers pertinent to a consideration of the age and correlation of the "older basalt" have been published.

In 1959 Durrell (1959, 1959a) published the results of an extensive study of certain of the basaltic lava flows (previously mapped as "older basalt" by Turner) in the northern Sierra Nevada. Durrell assigned these flows to a newly named stratigraphic unit called the "Lovejoy Formation", which he believed to be upper Eocene or lower Oligocene (p. 214-216).

Dalrymple (1964, p. 14), on the other hand, obtained an absolute (potassium-argon) age of 23.8 million years (lower Miocene) on rocks below the "older basalt" (Lovejoy Formation) at South Table Mountain. Using this determination and a date (22.2 m.y.) obtained from strata above the Lovejoy Formation near Blairsden, California, Dalrymple (p. 15) concluded that the "older basalt" or Lovejoy Formation is lower Miocene (Arikareean).

The term *New Era Formation* is proposed for these fluviatile deposits. The New Era mine (recently renamed "Jack and Jim mine"), which lies near the head of Dry Creek (sec. 1, T. 21 N., R. 3 E.), is considered to be the type locality. There the conglomerate and interbedded finer-grained sediments cover a comparatively large area and are better exposed than in any other part of the quadrangle. The central part of the section is well-exposed in an old hydraulic-face on the New Era property, and the remaining portion above and below may be observed at the portals of adjacent mine openings.

In areal distribution, the New Era Formation is comparatively unimportant and crops out only on the walls and floors of steep canyons, where the base of the overlying Tuscan Formation has been exposed by erosion. Undoubtedly, however, much of the Tuscan in the northwest quarter of the area is underlain by strata equivalent to the New Era. The most important outcrops of the formation are in the upper part of Dry Creek. A somewhat larger area is probably underlain by the New Era along Butte and Little Butte Creeks, but outcrops there are quite scarce, and the contacts with the underlying and overlying formations may be mapped only within rather broad limits of error. The formation is also exposed in small areas on the east edge of Jordan Hill, on the west side of Gold Flat, and at several points just west of the West Branch from Cape Horn to the north edge of the area.

North of the Oroville quadrangle several stream channels and the sediments contained therein have been preserved beneath the Tuscan beds. These have become known mainly through the many gold-placer mines which have been opened into them. One of the best known examples is the Magalia Channel and its tributaries which Lindgren (1911, pp. 90-93; pl. 14, p. 84) described. Lindgren traced this channel for about 18 miles from Centerville, on Big Butte Creek, north-northeast to a point east of Barnum Hill. The sediments themselves were briefly described by Lindgren, but their relationships to the adjacent rocks strongly suggest that they are correlative with the New Era Formation.

Coarse pebble- and cobble-conglomerate is the most characteristic rock of the New Era. Its dominant color is light reddish-brown, the color of the matrix, set against which are dark blues and greens of the contained clasts. Bedding is rather ill-defined, and is usually obvious only where finer-grained sediments are interbedded with the conglomerate. The conglomerate is generally rather ill-sorted in respect to both size and composition of clasts present. The pebbles and cobbles are dominantly subangular, a lesser amount are subrounded, and a few are angular or rounded. Over a quarter of the pebbles have a flattened, discoidal shape. The cobbles, on the average, are less than 3 inches across, but cobbles of 5 or 6 inches are very common. Almost all of the pebbles and cobbles are composed of metamorphic rocks derived from the "Bedrock series". The most characteristic type is a bluish-gray, fine-grained amphibolite, similar to rocks of the same type which occur in place east and north of Jordan Hill, in the northeastern part of the area. The amphibolite alone accounts for about a quarter of the clasts at the type locality, and is very abundant at all other localities where the formation is recognized. Slate and slaty chert, typical of the Calaveras Formation, are nearly as common, while massive chert of varying color and strongly weathered serpentine occur in somewhat lesser amounts. Other rocks typically represented in minor quantities are white quartz, quartzite, weathered chlorite schist, altered dense basic volcanic rocks, and meta-gabbro. A few pebbles of diorite and quartz diorite are present in most outcrops. Subangular cobbles derived from the "older basalt" are rare at most localities, but their presence is significant in the dating of the New Era sediments. However, at the old Welch hydraulic mine, about a mile north-northeast of Pentz, 5 feet of coarse pebble- to cobble-conglomerate directly underlying the basal Tuscan beds and probably belonging to the New Era Formation contain abundant fragments of the "older basalt". No other recognizable Tertiary volcanic rocks were found as clasts in the conglomerate. The matrix of the conglomerate consists of reddish-buff, uncemented, friable, medium- to coarse-grained sand. Where the conglomerate rests on bedrock and the contact may be observed directly, the lower few feet are seen to consist dominantly of coarse, angular rubble derived from the immediately underlying formation.

The sandstone and siltstone interbedded with the conglomerate constitute but a minor part of the formation. They occur in beds rarely over a few feet in thickness. The sandstone is the same as that which serves as a matrix for the conglomerate. It is reddish-tan, massive, uncemented and friable. It is dominantly medium- to coarse-grained, but grades locally into very coarse-grained types. Sorting with respect to size is moderate, and only a minor percentage of admixed silt is present. The grains are subangular to angular and consist chiefly of quartz; feldspar, biotite, and dark dense lithic fragments are present in lesser amounts. The siltstone is red, massive, and firm, and contains a notable percentage of sand. Flakes of weathered biotite and small chips of yellowish-white plastic claystone are locally abundant.

The New Era is everywhere overlain by the Tuscan Formation. If parts of the New Era ever existed which were not protected by Tuscan strata, they have since been eroded away. At the type locality of the New Era, the contact is conformable, and the topmost sediments of the New Era grade upward into the basal volcanic sandstone of the Tuscan. Apparently the earliest Tuscan sediments were added to the already overloaded New Era streams and the sediments of the two were deposited together. The New Era drainage was disrupted and soon volcanic (Tuscan) debris was deposited in overwhelming quantities. The gradational relationship between the New Era and Tuscan does not exist over the entire area where the two are in contact, however. At the old Welch hydraulic mine, for example, the contact between the two is conformable though quite sharp. Near Parish Camp, about one-half mile northeast of the Welch mine, several thin conglomerate beds containing abundant fragments of the "older basalt" are interbedded with volcanic sediments in the lower part of the Tuscan. The Tuscan there clearly abuts against a gently southwest-sloping bedrock surface (Fig. 37). These conglomerates may represent a sporadic renewal of sedimentation of the New Era type at a time when the bulk of the detritus entering the area (either as fluviatile sediments or volcanic mudflows) had come from typical Tuscan sources.

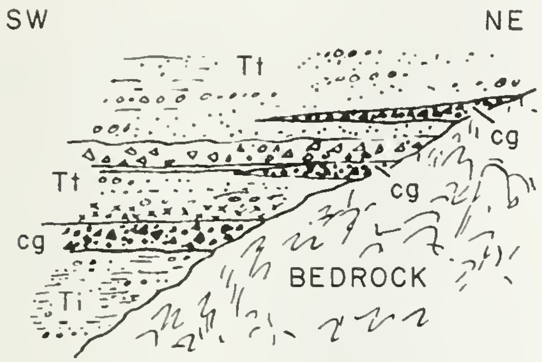


Figure 37. Diagrammatic section showing relationship of Tuscan strata to conglomerate beds containing fragments of "older basalt" near Welch hydraulic mine and Parish Camp. (Ti = Ione; Tt = Tuscan; cg = conglomerate with fragments of "older basalt".)

In the eastern part of the area, the New Era Formation is underlain with profound unconformity by the "Bedrock series". Along Dry Creek it is underlain in part by bedrock, but at the south end of the outcrop area the New Era abuts, with disconformity, against the Ione strata. On Butte and Little Butte Creeks, exposures of both the New Era and the underlying Chico sediments are so poor that the stratigraphic relationship between the two cannot be discerned. It is probable, however, that the two are separated by a slight unconformity. North and west of the mapped area, the Chico strata are known to be overlain unconformably by the Tuscan, and since the New Era is in comformable and, in part, gradational relationship with the Tuscan, it follows that the New Era as well might be expected to overlie the Chico unconformably.

Because most of the New Era Formation occupies stream channels, its thickness usually varies rapidly along strike. The thickest section was observed along the west side of, and below, the thin cap of Tuscan strata which occupies the western part of Gold Flat. Here, the New Era Formation is about 100 feet thick, and extends for approximately 3000 feet along strike. At the type locality, the New Era mine, the formation reaches a maximum thickness of 90 feet, gradually thinning out both to the north and south. The strata there appear to lie in a broad, shallow, southwest-trending channel, whose width is approximately 6000 or 7000 feet. The thickness of the New Era on Butte and Little Butte Creeks is estimated to be around 60 feet, and does not appear to vary markedly within the mapped area.

The New Era Formation is believed to represent fluviatile deposition upon a floodplain and in upland stream channels. In the eastern part of the area outcrops of the New Era continue for comparatively short distances along strike, and appear to have filled short segments of channels which were cut in the underlying bedrock and were subsequently blanketed by the Tuscan volcanic deposits. The overall coarse nature of the New Era sediments and the fact that they appear to have filled channel-like depressions suggest that they represent fluviatile deposits. To the west, along Dry Creek, the sediments occupy a channel much broader and relatively more shallow than any found in the area to the northeast. Farther west, on Butte and Little Butte Creeks the formation does not appear to have filled any definite channel and shows no marked variation in thickness throughout that part of the area. There, the formation was apparently laid down on a broad floodplain to which sediments were furnished by streams flowing in the channels to the north and east. These deposits are probably continuous with those described by Lindgren (1911, p. 91) at Centerville, on Big Butte Creek, about 3 miles north of the north edge of the area. Lindgren believed that these accumulated at the lower end of the Magalia channel, apparently in a broadened channel or upon a floodplain.

The composition of the pebbles and cobbles present in the conglomerate indicates a provenance largely of bedrock metasedimentary and metaigneous rocks not unlike the rocks that are at present exposed in the higher parts of the area. Flows of the "older basalt", probably continuous with that which caps Oroville Table Mountain, were present in the source area, and these were at least in part eroded and contributed a minor amount of sediment to the New Era channels. Many of the quartz pebbles found in the conglomerate were probably derived largely from Eocene quartzose sediments which presumably cropped out in part of the source area. Mechanical, rather than the chemical, weathering appears to have dominated in the upland region which furnished detritus to the New Era streams. The strongly weathered serpentine pebbles may have been derived from an area where the products of deep chemical decay of the pre-Ione period had been, until that time, preserved beneath a cover of Eocene sediments and "older basalt".

Movement and deposition of coarse debris in the stream channels and upon the floodplain were brought to a halt by the invasion in late Pliocene (Tuscan) time of overwhelming quantities of volcanic mudflow material and closely related volcanic sand and gravel. The extent to which the disrupted streams furnished detritus to be mixed with the Tuscan sediments is not known, but apparently the quantity was negligible, since non-volcanic pebbles and cobbles are relatively scarce in the Tuscan.

No fossils were found in the New Era Formation by the writer, so that the determination of its age is based upon stratigraphic relationships and upon the lithology of the New Era sediments. The youngest formation overlain by the New Era is the Ione (middle Eocene). It is evident, however, that the New Era occupied a broad erosional channel cut in part into the Ione, suggesting that a considerable time gap existed between the periods of deposition of the two formations. This inference is strengthened by the fact that the two units, respectively, represent deposition in markedly contrasted environments. However, the most important line of evidence in establishing the age of the New Era is the presence in that formation of fragments of the "older basalt", showing that the New Era definitely post-dates the "older basalt". The "older basalt" is thought to be at least as young as early Pliocene, so that the New Era is probably no older than early Pliocene, and may well be middle or late Pliocene *.

The New Era is overlain by the Tuscan Formation (upper Pliocene) and is, therefore, clearly older than the Tuscan. As noted above, the contact between the two is gradational in at least one locality, and at others sediments, identical with those of the New Era, are interbedded with normal Tuscan strata in the lower part of the Tuscan section. These relationships strongly suggest that the age of the New Era does not differ markedly from that of the Tuscan and thus may be entirely or in part late Pliocene.

### Unnamed Rhyolitic Pumice Tuff

Several miles east of Oroville, light-colored rhyolitic tuff and pumice-lapilli tuff are exposed in roadcuts along the Oroville-Forbestown highway. These rocks are nearly flat-lying and clearly belong to the "Superjacent series", but their age is known only within rather broad limits. They may be in part equivalent to the "tuffs of Oroville" described by Lindgren (1911, pp. 26-27, 90). However, this term seems inadequate for several reasons. First, Lindgren's definition of the "tuffs of Oroville" was rather vague, and it appears that Lindgren may have also included certain parts of the andesitic rocks questionably referred to the Mehrten Formation by the present writer. Second, the term has little regional stratigraphic significance and does not appear to have been adopted to any appreciable extent by other writers on Sierran geology. Finally, the name "Oroville" was preoccupied as a stratigraphic term prior to its use by Lindgren; the name "Oroville beds" was used for the Monte de Oro Formation by Fontaine (1900, p. 342). No formational name is proposed by the present writer for these rocks, principally because of the uncertainty regarding their exact stratigraphic position and because they are of such limited areal distribution within the quadrangle. It is possible that the exposures in the Oroville region do not represent the maximum development of this unit in the Sierra Nevada, and that there exist localities better suited to the study and naming of these rocks.

Regarding the "tuffs of Oroville", Lindgren (1911, pp. 26-27) stated:

> Along the foothills [of the Sierra] from Bear River to Feather River a series of light-colored tuffaceous rocks are exposed in places, although the formation is generally covered by later Quaternary gravels or by the red soil of the valley . . . near Oroville they are extensively developed and form the low flat-topped hills which flank the river on the south side for a distance of 8 miles below Oroville. . . . The tuff extends under the present alluvium of the Feather River and forms the bedrock of the area now worked so extensively by dredging. It is a compact light brown material, containing in places pebbles of metamorphic rocks and also small white fragments of pumice which are found to consist of volcanic glass; locally these fragments are very small and the tuff looks more like a compact clay. Bore holes 80 feet deep have been sunk in it in the flood plain below Oroville without finding different material. On the road to Wyandotte from Oroville similar material outcrops in the low foothills underneath the Quaternary gravel up to elevations of about 400 feet. . . . The bedrock relations at Oroville indicate that this series was deposited on the even slope of the older (Neocene) formations, before the modern canyon of the Feather River had been excavated but after the earlier Ione formation had been greatly eroded.

The only tuff known by the writer to be exposed in the banks of the Feather River below Oroville is that just east of Thermalito. This is clearly andesitic in composition and was mapped as Mehrten (?). It is, however, lighter in color and finer-grained than most of the other Mehrten (?) andesitic rocks exposed in the area. Thus, from Lindgren's statement regarding the "tuffs of Oroville" at the Oroville dredging ground, it would appear that he included some of the Mehrten (?) andesitic material, as well as the rhyolitic pumice tuff described here, in his definition of the "tuffs of Oroville".

The principal rock type composing this unit is vitric tuff, often interstratified with which are thin layers containing abundant lapilli of white pumice. The tuff is characteristically light-colored. Most of it is white, light gray or pale buff, though certain beds are locally discolored by an orange-brown ferruginous stain. Much of the formation is thin-bedded and some indi-

* Since the preparation of this manuscript, the "older basalt" has been shown to be probably lower Miocene so that the lower age limit of the New Era must be extended to Miocene.

Figure 38. Rhyolitic pumice tuff. *Left,* Glass shards from vitric tuff. Outcrops on Oroville-Forbestown road. X 100. *Center,* Pumice fragment from pumice lapilli tuff. Outcrops on Oroville-Forbestown road. X 175 *Right,* Fibrous pumice from pumice sandstone(?). Outcrops between Oroville and Sycamore Hill. X 60.

vidual units exhibit excellent cross-bedding. The tuff is usually well-sorted, and shows all gradations from silt- and sand-sized tuff to lapilli tuff. The finest-grained types are usually well-consolidated and "chalky", and consist almost entirely of angular glass shards. Under the binocular microscope, the shards are seen to be delicately shaped, and consist of connected, thin, curving septa of clear glass (Fig. 38a). The coarser-grained tuff and lapilli tuff are extremely friable and crumble readily under slight pressure. They consist principally of volcanic glass in the form of white, unaltered pumice. The sand-sized particles and lapilli are mostly angular to subangular, and some are subrounded, presumably reflecting the aqueous transport to which the original ash was slightly subjected. Lapilli, which measure up to 4 centimeters, are generally concentrated along certain beds, but most of the tuff contains scattered lapilli. Accompanying the pumiceous material in the coarser-grained tuff and lapilli tuff are small angular fragments of euhedral crystals of quartz, glassy feldspar (sanidine), hornblende and hypersthene, with a few chips of dark, dense, volcanic (?) rock.

Under the microscope, the tuff is seen to consist almost wholly of clear to slightly altered volcanic glass, present either as angular shards or as slightly rounded grains of pumice. Much of the pumice has a distinctly fibrous appearance, but in some, the vesicles are spheroidal (Fig. 38b). The glass most commonly is colorless; less commonly it is tinted pale green or yellow. Angular crystal fragments, the size of fine sand or silt grains, occur sparingly. Most of them are feldspar—oligoclase-andesine and possibly sanidine—but a few grains of epidote, clinozoisite, and certain ferromagnesian minerals are present as well. The refractive index of the glass, determined by oil-immersion methods, varies from 1.505 to 1.511 ± .003, indicating silica percentages ranging from about 67 to 69 (George, 1924, pp. 364-365), and a rhyodacitic composition. A heavy mineral concentrate from the tuff exposed on the Forbestown road consists largely of blue-green to olive-green hornblendes, lesser amounts of hypersthene, epidote, clinozoisite, and magnetite, and a few grains of zircon, actinolite, oxyhornblende, and augite.

A few outcrops of the tuff are along former U.S. highway 40 (alternate) at the north end of the same hill in which the main exposures are seen on the Oroville-Forbestown highway. At the most, only a few feet are exposed, and the base of the unit is not seen, due largely to a cover of Quaternary sediments. No andesitic material is in evidence in the immediate vicinity, but it may underlie the tuff here as it does to the south. Three-quarters of a mile southwest of Sycamore Hill is a low bedrock knob capped by 20 or 25 feet of what appears to be normal buff thin-bedded firmly consolidated sandstone. Under the hand lens, however, this rock is seen to consist entirely of medium- to coarse-grained sand-sized angular fragments of tan, "woody" pumice (Fig. 38c). The refractive index of the fresh glass is 1.500 ± .003, indicating a rhyolitic composition. This occurrence probably represents an isolated outcrop of the rhyolitic pumice-tuff described above.

Because they appear to be the products of explosive volcanism, it is believed that these deposits covered a much wider area immediately following their emplacement. The limited areal distribution shown by these rocks today is due largely to later erosion and to masking by later deposits.

The rhyolitic tuff seen on the Forbestown Road rests on andesitic mudflows of the Mehrten (?) Formation. No marked angular discordance exists between the two units, and the contact, which was not directly observed by the writer, may be an erosional disconformity. This suggestion finds questionable support in the fact that the Mehrten (?) strata on South Table Mountain and on Monte de Oro lie approximately 500 feet above the general level of the rhyolitic deposits east of Oroville. It is thus possible that the rhyolitic material infilled a broad channel which had been previously excavated into the Mehrten (?) rocks. An alternative possibility is that the rhyolitic tuff is interbedded with the Mehrten and that any overlying andesitic material, more or less equivalent to the stratigraphically higher andesites now found on Table Mountain, was eroded away prior to the deposition of the Red Bluff Formation. The rhyolitic tuff is overlain disconformably by the fluviatile deposits of the Red Bluff Formation. The 15 feet of tuff exposed east of Oroville is cut out completely within a few hundred feet to the west, where the Red Bluff rests directly on the Mehrten (?) andesitic rocks.

The tuffs are the product of explosive volcanic activity. The original pyroclastic materials appear to have been subjected to a small amount of aqueous transport, as evidenced by prominent cross-bedding seen in certain strata and by the slight rounding shown by the larger fragments. The present deposits, with their minor sedimentary aspects, may represent material eroded and slightly reworked by running water from original subaerial pyroclastic accumulations, volcanic ash which settled from the air directly into a lake or river system, or perhaps a combination of both. An estimation as to the actual geographic location of the volcanoes whence the pyroclastic material was erupted is not possible in the light of the meager data at hand. The present writer is of the opinion that the source area lay somewhere to the east, but this is little more than a guess. Lindgren (1911, p. 90), pointed out the likelihood "that ash showers from the neighboring volcano of the Marysville Buttes" contributed to the formation of the "tuffs of Oroville". However, as pointed out by Clark and Anderson (1938, p. 940), "Williams, in his study of the Marysville [Sutter] Buttes [1929, pp. 109, 139] has shown that the acid rocks of the Marysville Buttes are intrusive and did not contribute juvenile pyroclastic material to the neighboring basin of deposition." It is probable that a regional study of the tuff from Oroville south to Bear River, with particular attention paid to variation in average size of fragments and to thickness from section to section, would shed considerable light both upon the direction, and perhaps location, of the source area and upon the exact stratigraphic position and age of this unit.

Little direct evidence bearing on the age or on the definite correlation of these deposits with Tertiary volcanic rocks of similar character in Northern California is at hand. The fact that here rhyolitic tuff overlies andesitic mudflows at once raises a problem, for exactly the reverse sequence is generally the case throughout the northern Sierra Nevada. However, the uncertainty regarding the age of the andesite near Oroville has already been pointed out. If the andesitic material is as old as, or older than, lower Oligocene (cf. "Reeds Creek andesitic rocks" of Clark and Anderson, 1938), the rhyolitic tuff under discussion may well correspond to the rhyolitic tuffs (cf. Valley Springs) found in other parts of the Sierra Nevada. Its age, then, would be Miocene (?). If, on the other hand, the andesite at Oroville is correlative with the younger Sierran andesites (Mehrten Formation of some areas), the rhyolitic tuff here can hardly be equivalent to pre-Mehrten rhyolitic deposits. Furthermore, if the rhyolitic tuff here is actually correlative with the other Sierran rhyolitic rocks, it is curious indeed that Lindgren (1911, pp. 26-27, 90), familiar as he must have been with other Sierran rhyolites in general, apparently saw little in the rocks at Oroville to convince him that such a correlation might exist.

The fact that at least a limited amount of rhyolitic volcanic activity followed the eruption of the Mehrten andesitic rocks in the Northern Sierra Nevada has been shown by Curtis (1951, pp. 181-186), who described several rhyolite necks which clearly intrude the Mehrten deposits near the summit of the range in Alpine County. As yet, no such intrusive bodies have been discovered farther to the north. However, most of the geologic work done in higher parts of the northernmost Sierra has been more or less of a reconnaissance nature (cf. Diller, 1908; Turner, 1897, 1898), and it is possible that rhyolitic conduits, similar to those found in Alpine County, do exist in this part of the Sierra and that from such conduits the rhyolite pumice tuff under discussion was ejected.

The present writer believes that the tuff is probably closely related in age, if not in source, to the Nomlaki Tuff Member of the Tuscan Formation, for the two are of similar appearance, and both contain hornblende and hypersthene as principal accessory minerals. Furthermore, there is some overlap of the range of refractive index of the glass found in the Nomlaki (Anderson and Russell, pp. 246-247) and of the glass making up the tuff at Oroville. The nearest exposures of the Nomlaki are in the northwest part of the Oroville quadrangle, approximately 15 miles from the deposits under discussion, and intervening outcrops were not found. Lindgren (1911, pp. 26-27), describing the "tuffs of Oroville", noted that similar deposits occur more or less continuously as far south as the Bear River. This might indicate that the source lay to the south and east of Oroville and some distance from the supposed source of the Nomlaki tuff. Even so, the two may belong to the same general period of volcanism and the tuff at Oroville may, like the Nomlaki, be late Pliocene in age.

### Tuscan Formation

The Tuscan Formation is areally the most important unit mapped in the Oroville quadrangle. It consists exclusively of volcanic rocks and their sedimentary derivatives. These deposits were early described by

Figure 39. Tuscan Formation in canyons of Butte and Little Butte Creeks, as viewed from Honey Run. Alternating tuff-breccia and volcanic sediments. View west.

Whitney (1865, p. 206). Diller (1889, p. 442) was the first to give a detailed description, and later (1895) named the Tuscan Formation for Tuscan Springs, in Tehama County, where the unit is well-exposed. In a later paper, Diller (1906) used the term "Tuscan tuff" and this nomenclature was followed by later writers. An extensive study of the Tuscan was made by Anderson (1933) who, because of the diversity of the deposits and the minor importance of tuff in the unit, advocated a return to the original term "Tuscan Formation" rather than "Tuscan tuff".

The Tuscan Formation is well exposed over much of the northwestern portion of the Oroville quadrangle. Most of the exposures lie west of the West Branch. Here it underlies a broad, dissected constructional plain which slopes gently toward the south and southwest (Figs. 2, 4) and passes beneath the overlapping alluvium of the Sacramento Valley at the approximate latitude of Pentz. Scattered erosion remnants of the Tuscan protrude south of this line as small mesas. The streams which have cut their way northward and northwestward back into the Tuscan have formed several deep canyons. These afford spectacular views of the internally stratified nature of the deposits which underlie the plain (Fig. 39). The strata are nearly flat-lying. Dissection of the plain has developed a well-marked consequent drainage pattern, characterized by deep, steep-sided, narrow canyons separated by equally long and narrow, fingerlike ridges. Some of the ridges pass uninterrupted beneath the alluvium of the Sacramento Valley; others break into a series of "knobs" (Fig. 40). The total effect is a subparallel arrangement of canyons and ridge-crests, sloping southward at the east edge of the plain and southwestward at the west edge. East of the West Branch outcrops of the Tuscan are restricted to ridge-tops just east of the river. These include a fairly large area on Jordan Hill and two small areas near Gold Flat. The exposures of the Tuscan Formation in the Oroville quadrangle mark the southernmost areal extent of this unit.

The Tuscan Formation, in the mapped area, is principally tuff-breccia, lapilli tuff, volcanic conglomerate and sandstone, with lesser quantities of tuff, claystone, and siltstone. Individual members are quite consistent along strike and lensing-out of any unit is usually rather gradual. Because of its resistance to erosion and soil-forming processes, the tuff-breccia is the most striking rock type in the formation, and the casual observer might tend to overestimate its quantitative importance. It is estimated that the tuff-breccia and closely related lapilli tuff make up no more than perhaps 30 or 40 percent of the total section here. Volcanic conglomerate and volcanic sandstone are of about equal importance, each constituting approximately one-quarter of the formation. Tuff, tuffaceous siltstone, and claystone together form probably no more than 10 percent of the Tuscan.

All beds of tuff-breccia observed by the writer are over 3 feet in thickness, many exceed 6 feet, and a few reach 40 feet. The rock is hard and compact, massive, and shows a tendency to break into rough-sided equidimensional blocks. Fractures or weathered surfaces in the tuff breccia are quite irregular, due, in part, to the presence of variously sized hard lithic fragments included in a somewhat softer matrix (Fig. 41). Internal stratification is generally lacking, and at the few localities where it is developed tends to be quite ill-defined. Specimens of unweathered tuff-breccia are medium brownish-gray or dark gray-tan. The tuff-breccia consists essentially of angular to subangular blocks of dark-colored basaltic and andesitic lavas firmly held in a prominent to predominant matrix of comminuted volcanic rocks and scattered sand-sized crystal fragments. The lithic fragments are unsorted with respect to size, and range through tuff and lapilli

Figure 40. Beauty Peak, capped by Tuscan tuff-breccia which is underlain by bedded volcanic sediments. View north.

sizes (as defined by Wentworth and Williams, 1932, pp. 47, 40) up to blocks of several feet in maximum dimension. Blocks measuring over 6 feet are common, and one block of about 10 feet in length was found on Jordan Hill (Anderson [1933, p. 225] recorded a block 45 feet in length in the Tuscan Formation northeast of Red Bluff). The average maximum dimension of the blocks varies from place to place, but at most localities is approximately 3 or 4 inches.

Individual blocks contained in the tuff-breccia are all lavas of basic or intermediate composition. Basalts and basaltic andesites are abundantly represented, while fragments of hornblende andesite are rather uncommon. Anderson (1933, p. 226) noted that basalt is predominant over andesite in the Tuscan as a whole. At any one locality, many rocks of dissimilar appearance occur, but most may be classified among one of the several fundamental types mentioned above. The blocks nearly always carry a few vesicles, and many are highly vesicular. Flow-banding and trachytic structure occur less frequently, but with the vesicular structure and the overall fine-grained character of these rocks, attest the fact that the blocks have been derived chiefly from extrusive or near-surface volcanic rocks. Rocks other than the volcanic types described above are generally lacking in the tuff-breccia, but at one locality, near the base of the formation, a few waterworn pebbles of granodiorite and basic volcanic rocks of the bedrock type accompany the normal materials of the tuff-breccia.

Most of the blocks contained in the tuff-breccia are black or very dark gray, but a few, less than 10 percent of the whole, have been oxidized to dark shades of red or reddish-brown. At least three-fourths of the blocks are more or less vesicular. Many of them are microvesicular, but some contain spherical vesicles of 2 or 3 mm in length which occupy 30 to 60 percent of the total volume of the rock. Complete amygdules are rare, but many of the larger vesicles are lined with zeolite or clear opal. A few blocks contain numerous spherical vesicles, from 2 to 4 mm in diameter, which are lined with a film of aphanitic blue chloritic (?) material. Almost all the blocks are porphyritic with a microcrystalline or, less frequently, aphanitic groundmass. Phenocrysts make up from 20 to 70 or 80 percent of the whole, the average lying near 40 or 50

Figure 41 (above). Massive tuff-breccia. Tuscan Formation. Near Lime Saddle.

Figure 42 (below). Tuff-breccia underlain by volcanic conglomerate and sandstone. Tuscan Formation. Pentz road, near Lime Saddle.

percent. The most abundant types show small but conspicuous elongate or sub-equidimensional phenocrysts of plagioclase, with fewer but larger phenocrysts of augite and olivine and sometimes hypersthene. Types having augite or olivine as the only conspicuous phenocrystic ferromagnesian mineral are somewhat less abundant than those showing several ferromagnesians.

As seen under the microscope, the blocks and lapilli contained in the tuff-breccia are almost invariably porphyritic, and phenocrysts constitute from 20 to 70 percent of the whole. In the great majority of specimens, mildly zoned plagioclase ($An_{51}$-$An_{83}$, avg. $An_{65}$) is the principal phenocrystic mineral. Less often feldspar is restricted to groundmass microlites. The dominant ferromagnesian mineral is usually augite, which is often accompanied by hypersthene or by olivine, or infrequently by both. In a few cases, either hypersthene or olivine is the principal mafic constituent, but rarely are the ferromagnesian minerals the sole phenocrystic minerals. Small granules of magnetite are commonly disseminated through the rock. The blocks and lapilli show a wide variety of groundmass textures. In some rocks, microlites are absent and the groundmass consists solely of dark brown to black glass. Where the groundmass is hypocrystalline, the texture ranges from intersertal to hyalo-ophitic. In other cases, the groundmass is felty or pilotaxitic with intergranular pyroxene, olivine, and magnetite and a little interstitial glass, or with subophitic pyroxene. The matrix enclosing the blocks and lapilli consists, in part, of angular, sand-sized fragments of plagioclase and volcanic rocks, with lesser quantities of augite, olivine and hypersthene, and rare grains of green hornblende. These are set in a dusty, semiopaque, microcrystalline material of low birefringence. Locally, patchy masses of carbonate help to cement the aggregate.

Tuff and lapilli tuff are frequently associated with the tuff-breccia, and all gradations between the several rock types occur. These are generally of similar composition and differ essentially only in the size of fragments present. Specimens of the tuff and lapilli tuff are usually indistinguishable from those of the matrix of the tuff-breccia.

A considerable portion of the Tuscan Formation is composed of volcanic conglomerate (Fig. 42). Typically it consists of subangular to subrounded, occasionally rounded, ill-sorted pebbles, cobbles, and boulders of dark-colored volcanic rocks, set in a matrix of buff, coarse-grained, ill-sorted sand. The dark color of the clasts is generally obscured by a coating of clay and silt, materials present in small quantities in the sandy matrix. The average size of the clasts from outcrop to outcrop varies from 1 or 2 inches to 4 inches, although boulders up to 12 or 14 inches across are common. The conglomerate is rather friable and appears to lack significant amounts of cementing material. Its weak consolidation is a function of the consolidation of the matrix sand, which in turn depends upon the presence of silt and clay as intergranular matrix material.

The conglomerate usually contains thin, lenticular interbeds of sandstone similar to that described below, and often grades into normal sandstone units. At other localities, however, the contact between sandstone and conglomerate may be quite sharp, and frequently exhibits cut-and-fill relationships (Fig. 43). At several localities, conglomerate occupies channels cut into the top of tuff-breccia, indicating that some erosion preceded the deposition of certain of the sedimentary units.

The bulk of the pebbles, cobbles, and boulders making up the conglomerate, aside from their shapes, are markedly similar, if not identical, with the blocks

Figure 43. Volcanic conglomerate filling channels cut into volcanic sandstone. Sandstone contains pebbly stringers. Tuscan Formation, near Lime Saddle.

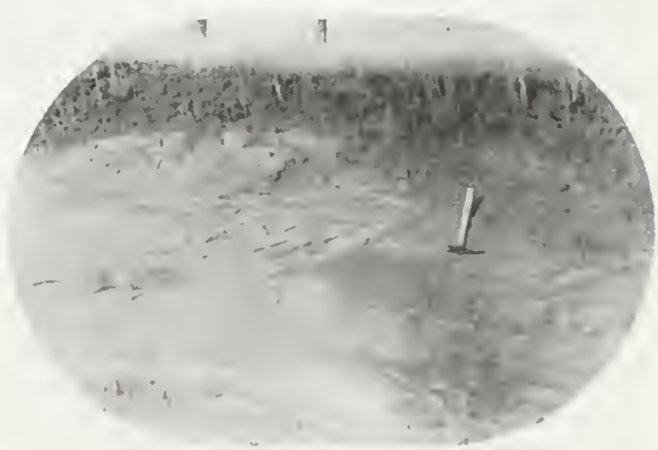

Figure 44. Cross-bedded volcanic sandstone in Tuscan Formation. Pentz-Durham road, near Clark road.

Figure 45. Thin-bedded volcanic sandstone and siltstone, overlain unconformably by old landslide(?). Large block in overlying material is tuff-breccia. Tuscan Formation, Clark road.

occurring in the associated tuff-breccia. All of these are of types generally attributed, at least in Northern California, to Cenozoic, rather than Mesozoic or Paleozoic, volcanism. The great majority are dark-colored, and all but a few are porphyritic with phenocrysts of one or more minerals set in a microcrystalline, sometimes aphanitic, groundmass. The two most abundant types are basalts or basaltic andesites containing abundant phenocrysts of plagioclase and augite or of plagioclase, augite and olivine; both may contain a few or many phenocrysts of hypersthene, and the two types together account for nearly 50 percent of the clasts examined. About 30 percent of the clasts contain no megascopically visible augite or hypersthene, but exhibit only plagioclase and olivine or olivine alone as phenocrysts. Those with olivine alone are typically quite vesicular. About 5 percent of the clasts show phenocrysts of feldspar only. Gray hornblende andesite, with phenocrysts of plagioclase and hornblende, constitutes no more than 2 or 3 percent of the pebbles examined.

The Tuscan sandstone varies from light gray or buff to dark orange-brown or dark gray. In fresh exposures the most common color is bluish-gray, which appears nearly black when the sandstone is damp. Much of it exhibits crudely developed thick bedding, some shows well defined bedding, and in the thinner-bedded types, excellent cross-bedding is often developed (Fig. 44). Bedding, where present, is usually manifested by changes in grain-size or by the presence of thin, discontinuous "stringers" of pebbles or granules (Fig. 43). In a few cases, the sandstone contains thin intercalations of light-colored tuffaceous clay or siltstone (Figs. 45, 46). Grain-size, even in a single outcrop, may be highly variable, and all gradations from very fine- to very-coarse occur. Sorting with respect to grain-size tends to be rather poor in the coarser-grained variety. A small amount of silt or argillaceous matter is invariably found to be present when the sandstone is pulverized. Most of the Tuscan sandstone, especially the coarser-grained type, tends to be quite friable and apparently owes its weak consolidation to minor quantities of silt or clayey material which accompany the grains. Some weak cementing may also be accomplished by a white chloritic (?) material which occurs as a thin film on the grains in much of the sandstone. It is also the presence of this film which in part accounts for the marked blue-gray color shown by some of the sandstone. The finer-grained sandstone at several localities is moderately well-indurated and tends to fracture into angular fragments. Subangular grains are almost always predominant in the sandstone, although some angular and subrounded grains are usually present.

In hand specimen, much of the Tuscan sandstone has a distinctly volcanic aspect. Identifiable grains include dark, dense lithic fragments, feldspar, augite, hypersthene and olivine. Under the microscope the Tuscan sandstone consists predominantly of volcanic rock fragments, petrographically similar to the rocks found in the tuff-breccia, and subangular grains of plagioclase. These are accompanied by lesser quantities of olivine (typically altered to iddingsite [?]), augite, and hypersthene, and by scattered grains of biotite and green hornblende. The grains are often thinly coated with an indeterminate microcrystalline mineral of very low birefringence.

At a few localities, rounded granules and small pebbles of pumice are present in the sandstone. At one point on Dry Creek, a single small spherical grain of perlitic volcanic glass was found. Refractive indices, determined by oil-immersion methods, of the glass range from $1.498 \pm .003$ to $1.511 \pm .003$, indicating a silica content of approximately 72 to 67 percent (George, 1924). A sandstone cropping out on the east bank of Little Butte Creek and lying about 50 feet above the base of the Tuscan exhibits crude bedding which is manifested by the presence of abundant fragments of white, partly devitrified pumice. It is probable that the pumice represents material reworked from the underlying Nomlaki tuff which crops out a short distance upstream from this exposure. The refractive index of the Nomlaki pumice is 1.503 ± .003; that of the supposedly reworked material is 1.505 ± .003. It is possible that the other occurrences of acidic pumice in the Tuscan can also be attributed to reworking of the Nomlaki tuff.

Siltstone and claystone are widely distributed in the Tuscan, but do not constitute a large porrion of the total section. They occur either as thin interbeds associated with coarser-grained sediments or as individual units several feet in thickness. They are usually light in color, ranging from light-gray or buff to brown and medium-gray. Both the siltstone and claystone are often thinly laminated, and thinly laminated alternations of differently colored siltstone and claystone are common. The laminations may either be planar and parallel or slightly curving and convergent. These sediments are typically compact and fairly hard, and tend to break with angular fracture into small, blocky fragments. Beds of massive soft brown clay occur at a few localities. Most of these finer-grained sediments have a tuffaceous aspect in hand specimen, and under the microscope abundant angular grains of fresh volcanic glass and bits of pumice may be seen. Scattered diatoms are invariably present.

Typical sections of the Tuscan Formation consist of thick units of sandstone, conglomerate, and finer-grained sediments or tuff with which beds of tuff-breccia of varying thickness are interstratified at rather widely spaced intervals. The tuff-breccia tends to form vertical or nearly vertical cliffs where its edges have been eroded, in contrast to the steep or moderate slopes formed on the sedimentary strata. Differential weathering has thus produced a step-like topography on slopes underlain by the Tuscan, and has served to grossly accentuate the large-scale stratification of the formation. This feature of the Tuscan is highly characteristic in the area of study, even when the formation is viewed from a distance of several miles (Fig. 2). Another characteristic feature of the Tuscan is the contrast between the relative density of vegetation growing on the tuff-breccia and that supported by the sediments and tuff. The tuff-breccia generally supports little else but grass and scattered oak and pine, while relatively thick brush usually grows on the sediments. It is probable that the thicker vegetative cover is favored both by the superior water bearing properties of the sediments, especially of the conglomerate and coarser-grained sandstone, and by the tendency of the sediments to form a thicker soil-mantle than that formed by the tuff-breccia.

In the western part of the area, the Tuscan Formation is underlain by flood-plain deposits of the New Era Formation. The contact is conformable and is locally gradational. The New Era also underlies the Tuscan in the upper part of Messilla Valley and at several localities on both the west and east sides of the West Branch and on the east side of Jordan Hill. In the lower part of Messilla Valley, the Tuscan is underlain with slight angular unconformity in part by the Ione Formation and in part by the Chico Formation. At the head of Messilla Valley and at most places in the canyon of the West Branch, the Tuscan rests with profound angular unconformity on the upturned edges of the Sierran "Bedrock series". The bedrock surface slopes southwestward, and the relatively flat-lying Tuscan beds onlap this surface from southwest toward northeast. Thus, the beds considered to be the base of the Tuscan in the northeastern part of the area are stratigraphically several hundred feet higher than those which are at the base of formation toward the west and south.

Over most of the area where it is exposed, the Tuscan Formation is the stratigraphically highest unit. At the southern edge of its outcrop area, however, the Tuscan is overlain by continental sediments assigned to the Pleistocene or Recent epochs. Oldest of these appear to be dissected alluvial fan deposits which partly cover the Tuscan rocks south of Dry Creek. The contact between the Tuscan and the younger, essentially flat-lying sediments is a slight angular unconformity, and in many places is also a strong erosional disconformity. For example, near Butte Creek the uppermost strata of the Tuscan lie 600 feet above Recent sediments. Just north of the Oroville quadrangle, at Paradise, a small remnant of a porphyritic olivine basalt, totally unlike the "older basalt" of Oroville Table Mountain, rests on the topmost beds of the Tuscan. This is possibly equivalent to the "younger basalt" mapped by Turner (1898) in the Bidwell Bar quadrangle. However, no volcanic rocks younger than the Tuscan were recognized in the Oroville quadrangle by the present writer.

Because the Tuscan Formation generally rests on a southwest-sloping bedrock surface, its thickness increases progressively toward the south and west. The thickest exposed section lies along Big Butte and Little Butte Creeks, where about 650 feet of interbedded conglomerate, sandstone, tuff-breccia and tuff occur. Along the west side of the canyon of the West Branch, the thickness of the Tuscan averages about 250 feet. On Jordan Hill, the maximum thickness is 250 feet, and near Gold Flat, no more than 75 feet are exposed.

Anderson (1933, pp. 245-261), after making an extensive survey of the literature concerning volcanic breccias and related subjects and considering the applicability of each of several possible modes of origin to the tuff-breccias of the Tuscan Formation, concluded that these deposits probably were emplaced as volcanic mudflows. For the water needed in the mobilization of the mudflows, he listed (p. 246) the following possible sources:

A. Eruptions
   a. Through a crater lake.
   b. Melting of snow and ice.
   c. Following heavy rains.
   d. Accompanied by heavy rains.

B. Not related to eruptions
   a. Collapse of the dam of a crater lake.
   b. Heavy rains falling on unconsolidated ejecta.
   c. Rapid melting of snow and ice. . . .

Anderson concluded that the initial source of the water in the case of the Tuscan mudflows was probably in large part melting snow. To the first (A) part of Anderson's list, Curtis (1954, p. 474) suggested the addition of "direct introduction of autobrecciated lava into streams". The nature of the sedimentary rocks which constitute a considerable part of the Tuscan section in the Oroville quadrangle strongly suggests that streams were quite active during most of Tuscan time and that therefore the process proposed by Curtis might well be in part responsible for the mobilization of the Tuscan mudflows.

Anderson (1933, p. 232) noted that the "outcrops of the Tuscan Formation converge and the beds thicken to the east . . . indicating without doubt that the source of the material must lie to the east of the present exposures". It may be further noted from Anderson's measured sections (Fig. 3, opp. p. 218) that the importance of tuff-breccia, in terms of percent of total thickness of a given section, increases toward the north and east from the westernmost and southernmost outliers, respectively, of the Tuscan Formation, and that the exposed sections composed entirely of tuff-breccia are concentrated in the area south and west of Lassen Peak. Anderson (1933, p. 233), after studying thin-sections of lavas of the Mt. Lassen area and considering the known age relations between these rocks and the Tuscan, further concluded:

> At present, all we may say is that the source of the Tuscan is apparently in old volcanoes that possibly existed in the vicinity of Lassen Peak; or they may have been located still farther east beyond the confines of Lassen Volcanic National Park and are now covered by later flows. Certainly the present volcanoes, so well developed in this region, are later in age and did not contribute to the Tuscan.

Recently, in the vicinity of Deer Creek (15 to 30 miles due south of Lassen Peak), Professor G. H. Curtis * discovered what he considers to be the source of a part of the Tuscan. There breccia dikes and breccia flows are intimately associated with tuff-breccias of the Tuscan. The mechanism of initial brecciation appears to have been identical with that recently postulated by Curtis (1954) to account for the pyroclastic debris of the Mehrten Formation.

It is considered unlikely that each individual mudflow corresponds to a specific volcanic eruption. More probably, some of the mudflows mark times when the conditions necessary for the movement of standing, previously erupted volcanic material were fulfilled (i.e. when mobility was imparted to existing debris in the source area), while others may have been derived directly from newly erupted material which had acquired the requisite mobility upon, or very shortly following, its extrusion.

The volcanic sandstone and conglomerate which are everywhere interbedded with the tuff-breccia were apparently deposited as stream-channel and flood-plain deposits and almost certainly derived the bulk of their materials directly from the mudflows themselves. The strongest line of evidence in this regard is the marked similarity, and in many cases identity, of rock types occurring in the conglomerate and in the tuff-breccia.

No fragments which might represent the matrix material of tuff-breccia were found in the conglomerate. Their absence is probably due in part to the fact that while the matrix is usually quite firm and compact, it is nonetheless considerably softer than the enclosed blocks. It may well be that the finer-grained volcanic sediments of the Tuscan contain in large part only detritus derived directly from the matrix of the tuff-breccia. Possibly little else was accomplished, then, by the agencies of erosion and transportation than to disaggregate the matrix of the tuff-breccia and liberate the blocks, and then to transport and slightly abrade and sort, according to size, the various materials available.

The deposition of the sediments occurred during times at which tuff-breccia, in the form of mudflows, was not entering the area. Blackwelder (1928) believes that non-volcanic mudflows in semiarid regions probably move as units "without . . . internal churning". Assuming that similar conditions of movement would prevail in volcanic mudflows, the emplacement of a particular mudflow at any given locality may be envisioned as being essentially instantaneous. Under such conditions of emplacement, the Tuscan mudflows without doubt severely disrupted drainage patterns over wide areas. Once a mudflow was emplaced, deposition of sediments was resumed under conditions similar to those which prevailed prior to the arrival of the mudflow, except that some changes in the details of the stream patterns must have come about. The siltstone and claystone which occur in the Tuscan at various localities are believed to represent deposition under lacustrine conditions. This contention finds support in the presence of thin laminations in most of the pelitic types, indicating the action of gentle currents operating in quiet waters. The presence of scattered

* Personal communication, 1955.

diatoms in most thin sections of these rocks also suggests lacustrine conditions. Apparently shallow, short-lived lakes formed from time to time on the broad flood plain over which the coarser-grained Tuscan deposits were spread. Whether all of the clastic particles were carried in by streams is not known, and it is possible that some of the material making up these rocks actually entered the depositional basin from the air as the product of explosive volcanic activity in far-removed localities. The volcanic glass present in these finer-grained types suggests that such may be the case. However, it remains to be demonstrated that, exclusive of the period of Nomlaki tuff deposition, explosive volcanoes were active during Tuscan time.

Anderson and Russell (1939, pp. 242-243) concluded that the topographic setting, general trend of stream courses, and conditions of deposition in the Sacramento Valley during the late Pliocene were essentially the same as those existing there today, except that contemporaneously with the sedimentation, volcanoes lying to the east of the basin were contributing the basaltic and andesitic material which makes up the Tuscan Formation. Russell (1931) noted that north of Red Bluff, the Tuscan and Tehama strata interfinger. A similar relationship presumably exists at other places where the two units are in contact.

Except for the diatoms mentioned above, no fossils were found in the Tuscan Formation by the present writer, nor is the writer aware of the occurrence of fossils at any place in the Tuscan. Russell and VanderHoof (1931, p. 14) concluded that the Tuscan is correlative with the Tehama Formation, found on the west side of the Sacramento Valley. This correlation is proven by the facts that the Nomlaki Tuff Member is present at or near the base of both formations and that the two units interfinger in their zone of junction. Since the Tehama is upper Pliocene, as based largely on a study of vertebrate fossils from that formation (Russell and VanderHoof, 1931; VanderHoof, 1933), the Tuscan must likewise be upper Pliocene.

#### *Nomlaki Tuff Member*

The Nomlaki Tuff Member of the Tuscan Formation crops out on the west side of the canyon of Little Butte Creek, about half-way between the juncture with Butte Creek and the mouth of Honey Run. There, it occurs as a thin, lenticular sequence of light-colored tuff and lapilli tuff at the base of the Tuscan Formation.

The name Nomlaki tuff was proposed by Anderson and Russell (Russell and VanderHoof, 1931, p. 14) for a distinctive dacitic pumice tuff present near the base of the Tuscan and Tehama Formations. The value of this member in proving the correlation between the two formations has been indicated above. The most important exposures of the Nomlaki lie on the west side of the northern part of the Sacramento Valley, but the unit also crops out along several streams on the east side of the Sacramento Valley (Anderson and Russell, 1939, p. 244). The most detailed published descriptions of the Nomlaki tuff to date are those written by Anderson (1933, pp. 234-235) and by Anderson and Russell (1939, pp. 243-247).

At the most, only about 20 feet of Nomlaki strata are exposed on Little Butte Creek. The principal lithologic types present are white to very light-tan pumice tuff and pumice-lapilli tuff. The tuff is thinly laminated and shows some small-scale cross-bedding. It consists predominantly of silt-sized shards of fresh glass ($n = 1.503 \pm .003$), accompanied by sparsely disseminated grains of dark ferromagnesian minerals (hornblende, hypersthene) and metallic minerals. Occasional thin beds of small, rounded fragments of fresh pumice accentuate the stratification. The lapilli consist exclusively of fresh white pumice, are subrounded to rounded, and grade into pumice-fragments of granule and sand size. The lapilli are set in a soft matrix of silt-sized glass shards and crystal fragments (plagioclase, hornblende, and hypersthene). Despite the soft nature of the rock, it is fairly firm and supports a low bluff several feet in height. The uppermost bed of the Nomlaki at this locality is a rock of similar composition to the purely pyroclastic rocks below, but which is orange-buff and considerably harder, and which contains a noteworthy admixture of sand. It apparently represents dilution of the pyroclastic debris by non-volcanic detritus.

Analyses of the Nomlaki tuff (Clarke and Hillebrand, 1897, pp. 194, 197; Diller, 1903, p. 360) show that the silica content lies between 65 and 70 percent, indicating a rhyodacitic composition (Nockolds, 1954, p. 1014). Anderson and Russell (1939, p. 246) noted that the glass contained in the tuff ranges in refractive index from 1.497 to 1.503.

Anderson and Russell (1939, p. 246) suggested that the Nomlaki tuff is the result of Peléan eruptions (*nuées ardentes*), and noted that in at least one locality, the tuff has apparently been welded. They believed (pp. 245-246) that the source of the Nomlaki lay east and south of Redding, near Bear and Digger Creeks. Unlike the Nomlaki tuff exposed near the supposed source area, the tuff mapped as Nomlaki along Little Butte Creek is distinctly stratified and in part quite thinly laminated, suggesting that it has been reworked to some extent by rather quiet (lacustrine?) waters.

### Red Bluff Formation

Outcrops of fluviatile sediments—principally conglomerate, with sandstone, siltstone, and clay—occur extensively in the southernmost part of the quadrangle. It is probable, on the basis of stratigraphic position and lithologic character, that a large part or all of these sediments are correlative with the Red Bluff Formation (Pleistocene).

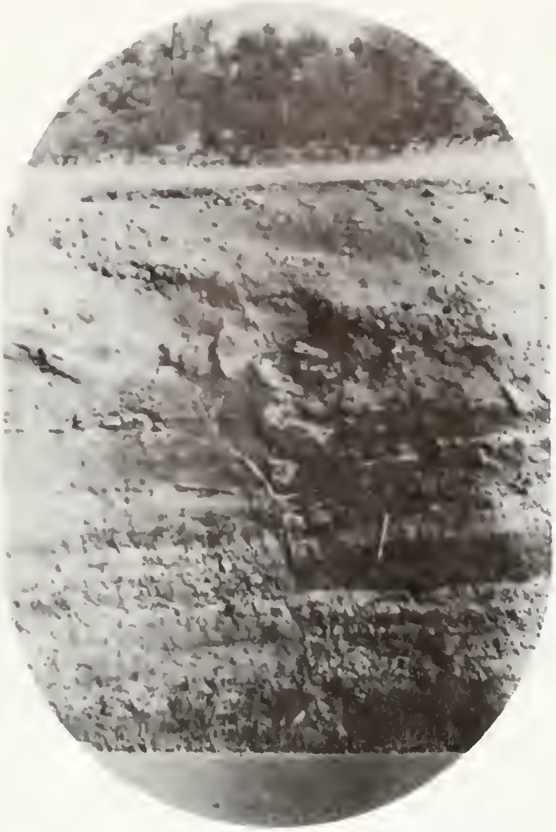

Figure 46. Thin-bedded volcanic sandstone and siltstone overlain unconformably by old landslide(?). Small normal fault transects beds. Tuscan Formation, Clark road.

The Red Bluff Formation was named by Diller (1894, p. 411), who stated that the formation is "best exposed on Red Bank * and at Red Bluff, on the Sacramento". Diller (1906, p. 6) later described the Red Bluff as it occurs in the Redding area, and brief descriptions of the formation have appeared from time to time in the later literature (Hinds, 1933; Anderson and Russell, 1939).

Outcrops of the Red Bluff Formation in the Oroville quadrangle are concentrated in the general vicinity of the point at which the Feather River leaves the foothills of the Sierra and flows into the Sacramento Valley. Southeast of the river the sediments underlie a rolling topography that includes elevations up to 600 feet. Immediately north and west of the stream they occur on well-defined terraces, the maximum elevation of which is approximately 375 feet. To the west, the terraces have been reduced by erosion to a series of low, rolling hills.

Most of the sediments mapped as Red Bluff are reddish-brown to greenish-tan. The various lithologic types occur in lenticular beds. Cut-and-fill relationships between adjacent units are common. Cross-bedding generally occurs in the finer-grained sediments.

The principal lithologic type in the Red Bluff is crudely stratified, ill-sorted pebble-to-boulder-conglomerate. The clasts are dominantly subrounded, but vary from subangular to well-rounded. Most of them consist of igneous and metamorphic rocks derived from the bedrock terrane. Recognizable Tertiary volcanic rocks are present in markedly subordinate quantity. The clasts are loosely held in a matrix of reddish-brown argillaceous sand.

Argillaceous biotitic feldspathic sandstone is commonly interbedded with the conglomerate. It is typi-

* About 10 miles west and slightly south of Red Bluff.

Figure 47. Red Bluff Formation resting disconformably on weathered bedrock. U.S. Highway 40 Alt. east of Oroville.

cally reddish-brown, thick- to thin-bedded, and quite friable. Lithic grains are locally abundant. In a few places, the sandstone is pale buff and contains closely-spaced thin laminae of blacksand (magnetite). Subordinate interbeds of reddish-brown or greenish-tan soft sandy siltstone and clay frequently accompany the sandstone.

The Red Bluff attains a thickness of at least 200 feet in the hills east of Oroville. The maximum thickness on the west side of the Feather River is approximately 125 feet. The Red Bluff rests unconformably on all older formations (Fig. 47), the youngest of which is the unnamed rhyolitic tuff that crops out near the Oroville-Forbestown road. A disconformable contact between about 50 feet of Red Bluff strata and the underlying Mehrten (?) Formation is well exposed in the west bank of the Feather River just east of Thermalito. At several localities on the east side of the river, the Red Bluff has buried low, flat-topped mounds of Mehrten (?) andesite which have since been exhumed by later erosion. Elsewhere, the Red Bluff is markedly unconformable on bedrock, and locally the pre-Red Bluff bedrock surface slopes as much as 10 degrees. The formation is disconformably overlain at many places by Recent alluvium.

The lithologic character of the Red Bluff Formation and the localization of the deposits at or near the point where the Feather River leaves the foothills suggest that the sediments were deposited on a flood plain and in channels by the river itself or by a closely related ancestral stream. The oldest deposits are those which lie to the east at the highest elevations and which have been most severely dissected. The sediments lying south and slightly east of Sycamore Hill appear to have been deposited in a south-trending channel. Thus, the river apparently turned sharply toward the south near Sycamore Hill, just as it does today near South Table Mountain. With subsequent uplift and downcutting, the river was able to breach the bedrock ridge on the west and to occupy a course more nearly approximating that shown by the present stream. The flood plain deposits of this and a still later stage in the history of the river are preserved in the well-defined terrace which lies north and west of Oroville. The northward and westward spread of these later sediments was impeded by the barrier of the Campbell Hills. Further uplifts in comparatively recent times have allowed the present streams to dissect the youngest deposits of the Red Bluff.

The Red Bluff Formation at its type locality is generally assigned to the Pleistocene. The present writer considers the deposits at Oroville which have been mapped at Red Bluff to be largely of Pleistocene age. It is possible that the oldest of these beds date back to the uppermost Pliocene, but definite evidence in this regard is lacking. The assignment of at least a part of the Red Bluff in the Oroville area to the Pleistocene is based on the close interrelationship between these deposits and the later stages in the development of the Feather River.

Small patches of stream-terrace deposits occur well above the present water level at many localities in the canyon of the West Branch. It is likely that many of them are correlative with the Red Bluff Formation mapped near Oroville. An interesting occurrence is that near Nelson Bar where about 15 feet of gravel lie more than 50 feet above the present river level. The gravel contains waterworn boulders up to 5 feet in diameter and rests on a potholed bedrock surface.

Figure 48. Foothills southwest of Pentz. Sloping surface in middle distance is capped by old fanglomerate(?), underlain by Chico sandstone. Ridges and buttes of Tuscan Formation in distance. View northwest.

### Fanglomerate

Alluvial material, much of it consisting of debris from the "older basalt" on Table Mountain and from the Tuscan Formation to the north and west, has accumulated on fan-like slopes at the foot of the west side of Table Mountain and westward to the center of the quadrangle. This material has been designated on the geologic map (Pl. 1) as fanglomerate.

The fanglomerate near Table Mountain consists almost wholly of subangular pebbles, cobbles, and boulders, up to 18 inches across, of the "older basalt". The material is uncemented but fairly firm and in places stands in vertical banks up to 12 feet in height. Toward the west, the proportion of debris derived from the Tuscan Formation gradually increases. Presumably the debris of the "older basalt" has been derived by fluviatile processes mainly from the large accumulation of talus and landslides at the edges of the basalt flow, while the Tuscan detritus has been added from the hills and ridges which partly border the fanglomerate on the north.

The maximum thickness of fanglomerate, where its base is actually exposed, is approximately 65 feet. It is expected that these deposits would thin out or interfinger with normal fluviatile deposits of the valley within a relatively short distance to the west and south. Slopes on the surface of the fanglomerate are generally steepest near Table Mountain, and a maximum slope of 265 feet per mile occurs near the north end of Table Mountain.

The fanglomerate clearly post-dates the Tuscan Formation since it contains detritus derived from the Tuscan and is underlain disconformably by the Tuscan at many localities. The fanglomerate has been dissected to some extent by the present streams and has been partly buried by Recent alluvium. It is probable, therefore, that at least a part of the fanglomerate is of Pleistocene, rather than Recent, age. It may be in part contemporaneous with the Red Bluff Formation mapped in the vicinity of Oroville.

Isolated accumulations of coarse, basaltic debris overlie Cretaceous sandstone just southwest of Pentz. These are tentatively designated as fanglomerate, although they are elevated above adjacent fans. They are thought to be remnants of an older fanglomerate which once covered a much larger area (Fig. 48).

### Alluvium

The term Recent alluvium is used here to cover all channel and flood plain sediments which are being deposited by the present streams, or which have been recently deposited and are now being eroded to some extent. Most of the southwestern quarter of the Oroville quadrangle is underlain by unconsolidated sand, silt, clay and gravel of the flood plain of the Sacramento River and its tributaries. Many of the larger streams in the area, such as Butte Creek, Clear Creek, and the Feather River below Oroville, have established narrow flood plains. Exceptions are the West Branch and its tributaries and the Feather River above the Oroville Bridge; these streams are cut in bedrock, but some sand and gravel has accumulated on their beds and on narrow beaches and bars. The only sizable area of alluvium on any of the tributaries to the West Branch is that along the upper course of Hodapp Creek at Gold Flat. The downcutting by this stream has failed to keep pace with that by the West Branch, so that while the lower part has an average grade of 1600 feet per mile, the upper course has a grade of only 135 feet per mile.

### Landslides

Most of the landslides mapped in the area are rockslides and rockfalls. The greatest number occur at the margins of the "older basalt" on Table Mountain and have already been described. Rockslides also occur in the area underlain by the Tuscan Formation and at the east edge of the quadrangle near Rocky Peak. Slumping and mudflow are important types of earth movement in the loosely consolidated, clay-rich strata of the Ione Formation and the "auriferous gravels." Much of the floor of the Cherokee mine is littered with debris which has slumped or slid from the steep hydraulic faces above (Figs. 49, 50).

### Mine and Dredge Tailings

Large parts of the flood plain of Butte Creek, Little Butte Creek, and the Feather River (at and below Oroville) are littered with piles of boulders and cobbles from dredging operations. The flood plain at the mouth of Sawmill Ravine is covered by unconsolidated quartz sand and pebble gravel which were washed down from the Cherokee hydraulic mine. High piles of "greenstone" boulders and cobbles—

Figure 49. Landslide from "auriferous gravels". West face of Cherokee hydraulic mine. View northwest.

waste materials from mining of the "greenstone gravel"—litter the floor of the channel at Cherokee (Fig. 21).

## STRUCTURE

Like other parts of the Sierra Nevada, the Oroville quadrangle is, in terms of geologic structure, a region of sharp contrast. The "Superjacent series" has been affected by mild upwarp and tilting, but the bedrock terrane has been subjected to intense folding, faulting, and metamorphism. Thus, as in the discussion on stratigraphy, it will be convenient to treat the structural features of the two units separately. In order to avoid a cumbersome wording of certain ideas, the writer will use the term Mesozoic in the discussion on bedrock structure to mean only those Mesozoic rocks which are a part of the bedrock complex of the Sierra. In this sense, the term Mesozoic will not include the Upper Cretaceous Chico Formation, which is part of the "Superjacent series". An interpretation of the structural features of the area is graphically presented in the structure sections.

### "Bedrock Series"

The structure of the bedrock terrane is dominated by a series of tightly compressed, in part overturned, folds. Stratification and metamorphic foliation alike are vertical or dip steeply toward the east or northeast. The average structural trend is approximately northwest but varies from N 60°W in the northernmost outcrops to nearly due north in the south part of the area. Two faults, presumably reverse, have been mapped in the southeast portion of the quadrangle.

*Folds.* Low-grade metamorphism and the isoclinal nature of the folding have rendered difficult the recognition of folds in the thick section of Calaveras strata. Therefore, the positions shown for most of the folds were determined largely on the basis of apparent repetition of distinctive rock units, augmented to a limited degree by the use of conventional criteria for the determination of stratigraphic sequence and by the continuity of certain stratigraphic units around anticlinal noses or synclinal troughs. The two largest folds thus delineated are an isoclinal, overturned syncline and an isoclinal, overturned anticline lying north of the West Branch. Both folds are slightly overturned toward the south. These folds together expose all of the thick Calaveras section known to crop out within the Oroville quadrangle. In addition, a considerable section of schistose metavolcanic rocks not included in the Calaveras by the writer is exposed beneath the Calaveras strata on the overturned north limb of the syncline. The segment of exposed bedrock in the northeastern quarter of the area is too short to obtain an accurate estimate of the amount of plunge of the two northernmost folds, but there is some suggestion that the syncline plunges slightly toward the southeast. However, the folds involving the Pentz Sandstone Member just south of Glover Ridge definitely show steep plunge toward the southeast, perhaps as high as 70 or 80 degrees. No reasonable explanation can be offered for the steep plunge of these folds. It is possible, however, that their configuration has been influenced by their proximity to the large intrusive (?) body of basalt porphyry at Glover Ridge.

Figure 50. Landslides from opposite sides of Cherokee hydraulic mine coalesced in Sawmill Ravine. View south.

Small-scale folding, directly observable in the field, occurs in the older bedrock terrane. In the northern part of the area, small folds in the unnamed schistose metavolcanics and in the enclosed metachert have nearly horizontal axes. Chlorite schist intercalated with the Calaveras slate near Nelson Bar and in the area to the southeast, however, shows steeply plunging small-scale folds.

It is believed that the initial folding of the Calaveras strata took place prior to the Nevadan revolution (Upper Jurassic), probably at or near the end of the Paleozoic. Evidence for late Paleozoic orogenic movements in California and Oregon has been summarized by Eardley (1947, pp. 329-330). Several lines of evidence within the Oroville quadrangle suggesting that such movements have occurred are as follows:

(1) The contact between the Jurassic Oregon City Formation and the underlying Calaveras strata appears to be a marked angular unconformity. However, it is considered probable that strong orogenic movements related to the Nevadan revolution have increased the angular discrepancy between the two units, and that the contact may have been the site of some displacement at that time.

(2) The basalt porphyry at Glover Ridge, thought to be a volcanic plug or neck intruded during the deposition of the Oregon City Formation, partly transects one of the steep-plunging folds in the Calaveras near Pentz. Here again, the folding was probably intensified at the time of the Nevadan revolution, but the lines of folding appear to have been established prior to the Nevadan.

(3) There is a marked difference in the degree of metamorphism between the Calaveras strata, bearing the imprint of low-grade regional metamorphism, and the Mesozoic rocks, only slightly metamorphosed except near localized zones of displacement.

(4) The trend of folds in the Oregon City Formation does not conform to the trend of folds in the underlying Calaveras, suggesting that the trend in the older rocks was established prior to the deposition and folding of the younger strata.

Perhaps the most striking, yet least understood, structural feature in the area is the Mesozoic-Paleozoic contact in the vicinity of Cherokee and Spring Valley Gulch. Because of the heavy accumulation of talus from the overlying Mesozoic volcanics which usually obscures the relationships, the contact can be located only within rather wide limits. It is clear, however, that the Mesozoic rocks are spatially above the Calaveras strata at all points, and the attitudes available indicate that they have been tightly folded along axes which strike nearly due north. The contact, at the few localities where it has been directly observed, is seen to be steeply dipping. However, the elevation of the contact does not appear to vary with topographic relief to the extent which might be expected if the folds had a gentle plunge. Alternative explanations for these relationships might be: (1) that the folds are actually steeply plunging, so that the plan of the outcrops more nearly approaches a true cross-section of the folds than would a section drawn in a vertical plane; (2) that, because of masking by talus, the rather simple overall configuration of the contact as mapped belies the complexity of existing folds, and the Mesozoic has actually been folded into a tightly appressed series of small, gently plunging folds; or (3), the contact, being a surface of division between rather incompetent slates and chlorite schists below and competent, more or less massive volcanic rocks above, has been the site of some dislocation which might have modified the original trace of the contact. The writer favors this third idea, although none of the alternative explanations is without some objection, and it may well be that no one of them alone explains all of the observed features. The folds in the Mesozoic near Monte de Oro and Sycamore Hill do not appear to be steeply plunging, and dips as low as 10 degrees have been measured on their axes. Thus, if the folds in the vicinity of Spring Valley Gulch are steeply plunging, a rapid flattening-out of plunge must occur in the intervening area. Unfortunately, structural data on the intermediate area is lacking, due largely to the massive nature of the coarse pyroclastics which dominate the Mesozoic section there. On the other hand, the presence of numerous, tightly appressed but gently plunging folds in the northern area seems incompatible with the rather wide spacing of folds seen in adjacent parts of the area. Objections to the alternative of dislocation along the contact would be the steep dip of the contact wherever it has been observed directly, and the lack of similar features, so far as known, in other parts of the Sierran bedrock.

Four folds occur in the Mesozoic in the southern part of the area. These are best exposed along the Feather River a few miles north and east of Oroville. The Monte de Oro Formation crops out in the trough of an isoclinal, overturned syncline, called the Monte de Oro syncline. The anticlines which flank the syncline are not as tightly folded and show a gradual steepening of dip away from their respective axes. It is probable that the differences observed between these folds is largely a function of the relative degree of competency of the strata involved. It is suggested that the Monte de Oro, because of its relative incompetency, yielded more readily to folding than did the more competent volcanics of the Oregon City Formation.

*Faults.* Only two major faults were mapped in the bedrock terrane. Both occur in the southeastern part of the area. The largest of these separates the unnamed Paleozoic (?) metavolcanics at the east edge of the quadrangle from the Oregon City Formation on the west. It trends more or less due north, but north of the High Rocks, it turns north-northeast and passes out of the area. The apparent movement is dip-slip, with the east side thrown upward against the west side. The east flank of the anticline which lies adjacent to the Monte de Oro belt has been partly cut off by the fault, so that the Monte de Oro beds are not repeated in any syncline lying east of the anticline. The configuration of the trace suggests that the fault is nearly vertical or dips steeply to the east, and is thus probably a high angle reverse fault.

A second fault lies at the east edge of the Monte de Oro syncline and transgresses the synclinal axis to the south. The trace of the fault and the adjacent stratigraphic relations suggest that it is a reverse fault which dips steeply toward the east. Near Monte de Oro, the fault parallels the bedding and forms the contact between the Monte de Oro and Oregon City rocks. To the south, the fault cuts across bedding in both units and transects the axis of the syncline at such an angle that oucrops of the Monte de Oro are entirely cut out a short distance south of the Feather River. The trace of the fault was not recognized south of that point, due largely to poor exposure and to close similarity of lithology on either side of the fault.

Some displacement of apparently small magnitude has occurred along certain of the mineralized veins which are common throughout the bedrock area. However, with the exception of the several deposits which lie near the east edge of the Monte de Oro belt, definite indications of major faults in conjunction with these were not found. It is also quite probable that some faulting, perhaps of large magnitude, has occurred along certain of the lines now marked by ultrabasic intrusions in the northeastern part of the area, but because of the more or less concordant nature of these intrusions, definite evidence of major faulting was not found.

All of the folds and faults involving the Mesozoic bedrock in this area are attributed to the Nevadan orogeny, which profoundly affected the entire region of the Sierra Nevada during the Late Jurassic (Taliaferro, 1942, pp. 95-105). To what extent the structures seen in the pre-Mesozoic rocks have been influenced by the Nevadan orogeny is not certain, however. The writer has suggested that at least the lines of the present folds in the older bedrock terrane were established before deposition of the Jurassic Oregon City Formation. It is probable, however, that such folds were intensified during the Nevadan.

### "Superjacent Series"

The profound angular unconformity at the base of the "Superjacent series" is the dominant structural feature of the area, since it marks the division between the low-dipping Upper Cretaceous and Cenozoic rocks and the steep-dipping or vertical bedrock structures. The "Superjacent series" is essentially a group of very low-dipping, nearly flat-lying strata. The regional dip is not over 2 or 3 degrees in a general southwest direction. Although no folds were mapped in the "Superjacent" strata, local irregularities and dips up to 15 degrees have been measured. However, it is more likely that these discrepancies are related to such features as cross-bedding, initial dip, and slumping than to any actual tectonic causes. Slumping is especially likely in the clayey, barely consolidated Eocene sediments. A fairly consistent regional attitude is shown by the top of the "older basalt" on Table Mountain. The strike varies from N 20° W to N 25° W and the dip from 1° 36′ to 2° 18′. Consistent attitudes were also measured in the Tuscan Formation through the determination of elevations at various points on certain beds of tuff-breccia.

The only faults known to involve the "Superjacent series" within the area are seen along Clark Road, several miles north of the junction with Durham Road. There, several small normal faults, with displacement amounting to but a few feet, cut the Tuscan beds. In every case, the north side is upthrown (Fig. 46). Evidence of movements in fairly recent times is provided by an exposure which lies near the Oroville-Forbestown highway, just off the east edge of the quadrangle. There, a vertical fault has thrown bedrock, on the east side, up against barely consolidated stream deposits of the Red Bluff Formation, on the west side. The stratigraphic displacement is at least 6 feet.

## GEOLOGIC HISTORY

The sequence of recorded geologic events in the area of study began with the deposition, probably during the late Paleozoic, of basic lava flows, ash and volcanic sand. Still later in the late Paleozoic, the region was part of the Cordilleran marine geosyncline. As the belt subsided, over 10,000 feet of alernating organic mud, sand, gravel, and large quantities of basic to intermediate fragmental volcanic material and lava rapidly accumulated. Most of these sediments and volcanics came from a tectonically active source which lay to the west. Not infrequently in the subsiding basin, conditions were favorable to the local accumulation of bedded chert and limestone. A few thin flows of dacitic lava were erupted during the deposition. Sills and dikes of ultrabasic and basic plutonic rocks may have been intruded into the strata at this time. At or near the close of the Paleozoic, sedimentation and volcanism were terminated with the collapse of the geosyncline. The sediments and volcanics were folded and were probably slightly metamorphosed. Some plutonic intrusions of rather limited extent may have been emplaced at this time. The evidence available indicates that the area was then uplifted and subjected to considerable erosion.

The sea apparently did not again enter the region until the early part of the Middle Jurassic. Deposition in the Middle (?) Jurassic sea commenced with the volcanic eruption of large quantities of basaltic and andesitic mudflow, ash, and lava, and the accumulation of sand and coarse gravel which were reworked directly from the newly erupted volcanics. At least 3,200 feet of volcanic rocks and interbedded sediments were thus deposited. What may have been one of the ancient eruptive centers lies in the northeastern part of the area, where it has been exposed by long-continued erosion. Others may be covered by later deposits.

As volcanism finally waned, deposition of normal detritus became increasingly important. Over 1300 feet of Middle Jurassic sediments—sand, coarse gravel, and carbonaceous mud—were eroded from a heavily forested western landmass and deposited in shallow marine waters. Much of the terrane exposed to erosion at this time probably consisted of the folded and metamorphosed rocks of the old Upper Paleozoic geosyncline. Although only the Middle Jurassic rocks are now represented in the Oroville quadrangle, sedimentation and volcanism in or near the region probably continued into Late Jurassic time.

Well before the end of the Late Jurassic, there was severe diastrophism which affected the entire region now occupied by the Sierra Nevada. The Mesozoic sediments and volcanics, as well as the underlying Paleozoic rocks, were tightly folded and overturned, broken by faults, and metamorphosed. Great batholiths of granodiorite and related rocks were intruded in nearby regions, and some small hypabyssal dikes were injected into the rocks of the immediate area. As a result of this diastrophism, known as the Nevadan revolution, the ancestral Sierra Nevada was uplifted and subjected to erosion, while the western land mass, which had furnished the sedimentary and volcanic material to the Mesozoic sea, was depressed and itself invaded by marine waters.

The newly formed mountains of the region were gradually worn down by various erosive agencies. It was not until the Late Cretaceous that shallow marine waters inundated the area from the west. Sand and minor quantities of mud and gravel were slowly carried from a low lying landmass into the transgressing Cretaceous sea. The sediments were shifted about and sorted by currents as they gradually piled up against a west-sloping bedrock surface. Unlike the marine deposition of earlier periods in the region, this accumulation of sediments was unattended by volcanism. Nearly 4000 feet of sediments accumulated within the area before broad uplift at or near the end of Cretaceous time forced the sea to withdraw. Mild erosion of the recently deposited strata occurred after their emergence.

During middle Eocene time, shallow seas transgressed upon a rather low-lying landmass. The climate had become much warmer, and dense vegetation covered most of the emergent parts of the area. Erosion and deposition were not markedly active. Thin deposits of mud and sand accumulated. On land, in response to humid tropical or subtropical climatic conditions and a thick cover of vegetation, chemical decay of the bedrock was intensified. Stripping of the surface by normal erosive processes did not keep up with the chemical weathering and eventually a deep mantle of decayed rock materials blanketed much of the region. Only the minerals stable under these conditions survived the weathering, while the less stable minerals were converted to hydrous aluminum silicates. Minor uplift and possibly some local emergence occurred. The streams of the period, which were flowing westward toward the sea, were rejuvenated to some extent. Increased erosion resulted, and stripping of the products of deep chemical decay commenced. Much of the finer grained material found its way to the ocean, where sand, clay, and some gravel and carbonaceous matter accumulated to form deltas, while coarser sediments were deposited in the channels and on adjacent flood plains of the westward flowing streams. Swamps covering small areas may have come into existence from time to time in the region. The shore line was ill-defined and shifted about frequently. Deposition was sporadically interrupted for short periods of time, perhaps in response to minor uplifts. In time, less deeply weathered parts of the bedrock were exposed and erosion in general slackened. The corresponding sediments reflect these changes.

Deposition was largely terminated by uplifts which forced withdrawal of the sea and caused some erosion of previously deposited strata. Marine sediments were deposited in late Eocene or early Oligocene time in an area 30 or 40 miles to the south, but any contemporaneous sediments in the present area probably accumulated under nonmarine conditions.

By Miocene time, a gently sloping, locally irregular surface had been formed in the region. Vast quantities of fragmental andesite were erupted from centers which lay in elevated areas far to the east. These eruptions represented the later phase of a volcanic cycle which began with the expulsion of rhyolite. Mudflows, formed from the andesitic debris and accompanied by volcanic sand and gravel, reached the area and filled any depressions which were present in the existing topography. During this volcanic period, a flow of basaltic lava, poured out perhaps from a fissure to the north or east, inundated a large part of the area. More andesitic debris covered the basalt in the region to the east, but is not known to have reached the present area as well.

A period of uplift and erosion followed the volcanism. Much of the basalt and the underlying strata in the northern part of the area were degraded by small streams of rather high gradient which flowed southwestward. Coarse debris of these rocks was deposited on a broad flood plain which lay west of the elevated region. In late Pliocene time, the explosive eruption of a small amount of acidic ash was closely followed by the influx from the north of enormous quantities of basaltic and andesitic debris. Much of this material reached the area in the form of thick, highly mobile volcanic mudflows, but the majority of it was deposited from debris-laden streams as volcanic sands and gravels. The lateral spread of all but the latest of these deposits was limited on the east by a series of bedrock ridges which stood above the volcanic flood plain.

By early Pleistocene time, the Feather River had established a course which occupied more or less the same position as does the present stream. Where the ancient river left the foothills of the range and flowed out into the Sacramento Valley, thereby losing some confinement, coarse gravels were deposited on a flood plain adjacent to the river. With further uplifts of the region, the river was able to downcut the earlier gravels and to deposit coarse gravel at successively lower positions. In response to these same uplifts, deep canyons were cut upon the late Pliocene volcanic plain and upon the bedrock terrane to the east, while coarse debris accumulated at the lower elevations on alluvial fans. Minor uplifts continued into fairly recent times and have slightly rejuvenated many of the streams.

## MINERAL RESOURCES

The present writer made no special study of the mineral deposits of the area except as was incidental to the geologic mapping. The mines and mineral resources of Butte County have been described in many reports of the State Mineralogist and, more lately, the State Division of Mines. The latest report is that by O'Brien (1949), and the reader is referred to this publication for a detailed and comprehensive account of the mining industry in the area. Although there is abundant evidence of former activity within the Oroville quadrangle, at only a few properties is mining actually in progress. Most of the inactive mines or prospects have apparently been abandoned, and underground workings, for the most part, have been allowed to cave.

The chief mineral produced in the area was gold, both as placer and as vein deposits. Placer methods included underground work, hydraulicking, dredging, and various small-scale surface methods, such as panning and sluicing. With the exception of the Tuscan Formation, all of the post-bedrock formations containing any large proportion of conglomerate or gravel have been worked or prospected for gold. An interesting by-product of placer gold mining in the area was diamond, and more diamonds have been found in Butte County than in any other county in the state. All of the vein deposits occur in the bedrock terrane, and much of the bedrock area is dotted with shallow prospect pits or adits.

Prospects for chromite have been opened in several of the larger serpentine bodies in the area. Many of the larger limestone bodies in the Calaveras Formation have been worked, and parts of old kilns still stand at a few of these.

Clay has been worked in the Ione Formation near Wicks Corner, and beds of what appears to be unprospected, high-quality clay occur in several parts of the Ione and "auriferous gravels". Low-grade coal was reportedly mined at an early date from the Ione Formation in Coal Canyon.

Several operators presently produce sand and gravel for local use from the flood plain of Sawmill Ravine and Dry Creek. At many places, these streams have been aggraded to a depth of several feet by tailings washed down from the Cherokee hydraulic mine.

There has been no noteworthy commercial production of building stone in the area, although the ruins of several old buildings at Cherokee are constructed from the local "greenstone". Road metal for local use has been taken intermittently by the County from the long belt of serpentine near Gold Flat. Much of the "iron crust" found at the Cherokee hydraulic mine could probably be utilized as ornamental stone, but, so far as the writer is aware, no attempt to extract it in commercial quantities has been made.

No petroleum has been produced commercially in the Oroville quadrangle, although two gas fields—the Durham field and the Chico field—lie less than 10 miles west of the western border of the quadrangle. The Chico gas field produces from the Upper Cretaceous, while the Durham field derives its gas from the Donahoe sand, a subsurface member of the Capay shale. A shallow well is supposed to have been drilled many years ago a short distance northwest of the Campbell Hills, but the writer has been unable to obtain any reliable data in this regard. Presumably, however, no production was obtained. Two dry holes were drilled in the Valley near the edge of the foothills in mid-1953. One, Cherokee Oil Company's Openshaw No. 1 (sec. 3, T. 20 N., R. 3 E.), had a total depth of 934 feet and bottomed in the Upper Cretaceous. The second, Humble Oil and Refining Company's S.F. Brown *et al* No. 1 (sec. 27, T. 20 N., R. 3 E.) was drilled to 1430 feet and also bottomed in the Upper Cretaceous. In the opinion of the writer, the most favorable sites for the entrapment of gas (or oil) in the quadrangle would probably be in the Cretaceous sediments which are truncated up-dip by the sloping bedrock surface below and by Tertiary strata above. Lateral closure might be effected by local irregularities in the bedrock surface or by faults or folds unrecognized at the surface.

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# APPENDIX A

## LIST OF MEGAFOSSIL LOCALITIES

## OROVILLE QUADRANGLE (Ed. of 1944)

| Locality Number on geologic map (Pl. 1) | University of California Museum of Paleontology Locality no. | Description of locality |
|---|---|---|
| | | **CALAVERAS FORMATION** |
| 1 | B-1507 | Dark gray limestone in lenticular body 1000′ long; about ½ mile ESE from Parish Camp and just W. of west branch of Feather River where the latter makes a sharp 90° turn to the east. Elev. 800′. N½SW¼ sec. 17, T. 21 N., R. 4 E., M.D.B.M. |
| | | **CHICO FORMATION** |
| 4 | A-9443 | Hard, lime-cemented sandstone. Bank of small gully 250′ N. of Pentz-Durham Rd., and 2375′ due W. from junction of that road with Pentz-Oroville Rd. Elev. 490′. NW¼NW¼ sec. 25, T. 21 N., R. 3 E., M.D.B.M. |
| 5 | A-9444 | Soft, buff sandstone. Same gully as locality no. 1. 250′ S. of Pentz-Durham Rd., and 2500′ S 76°W from junction of that road with Pentz-Oroville Rd. Elev. 475′. NW¼NW¼ sec. 25, T. 21 N., R. 3 E., M.D.B.M. |
| 6 | B-1245 | Hard, lime-cemented conglomerate. Gully flowing S. on S. side of Sausage Mtn. 5900′ N 11°W from B.M. 393. SW¼ sec. 24, T. 21 N., R. 3 E., M.D.B.M. Elev. 575′. |
| 7 | B-1246 | Hard, lime-cemented sandstone. Gully near W. edge of sec. 31, T. 21 N., R. 4 E., M.D.B.M. 4850′ S 46°E from B.M. 393. Elev. 550′. |
| 8 | B-1247 | Hard, lime-cemented sandstone. In bed of gully just above locality no. 7. |
| 9 | B-1248 | Soft buff sandstone. Same gully as locality no. 7. NW¼ sec. 31, T. 21 N., R. 4 E., M.D.B.M. 5000′ S 46°E from B.M. 393. Elev. 600′. |
| 10 | B-1249 | Hard, lime-cemented sandstone. Just above abandoned ditch on N. side of gully. 5150′ S 31°E from B.M. 393. SE¼ sec. 36, T. 21 N., R. 3 E. M.D.B.M. Elev. 500′. |
| 11 | B-1250 | Hard, lime-cemented sandstone (float). East-flowing gully in hills SW of Pentz. 1650′ N 48°W from B.M. 393. Elev. 475′. SW¼ sec. 25, T. 21 N., R. 3 E., M.D.B.M. |
| | | **"DRY CREEK" FORMATION** |
| 2 | | White to orange-stained, friable, pebbly, argillaceous sandstone. East bank of small gully at base of south side of South Table Mountain. 4400′ N 21°E from Butte County Hospital. Elev. 375′. N½NE¼ sec. 6, T. 19 N., R. 4 E., M.D.B.M. |
| 3 | | Light gray claystone. Roadcut on old county road from Oroville-Pentz highway to Cherokee. Elev. 625′. 6600′ S 28°E from B.M. 393. Near W. edge of SW¼SW¼ sec. 31, T. 21 N., R. 4 E., M.D.B.M. |

# APPENDIX B

## LIST OF PLANT FOSSIL LOCALITIES

## OROVILLE QUADRANGLE (Ed. of 1944)

| *Locality number on geologic map (Pl. 1)* | *Description of locality* |
|---|---|
| | "AURIFEROUS GRAVELS" |
| 12 | Reddish-brown, thin, platy, ferruginous siltstone, overlying 2′ lens of gray shale. Near base of Tertiary section on south bank of tributory to Sawmill Ravine. 1550′ S. 5°W from Sugarloaf. Elev. 1250′. S. edge of NW¼ sec. 33, T. 21 N., R. 4 E., M.D.B.M. |
| 13 | Gray, sandy shale-partings near base of buff, cross-bedded sandstone. 15′ ± stratigraphically below base of "older basalt" at main west face of Cherokee hydraulic mine. (See measured stratigraphic section, appendix C). 2600′ S 75°W from Sugarloaf. Elev. 1400′. Near center of NE¼ sec. 32, T. 21 N.,.R. 4 E., M.D.B.M. |
| | IONE (?) FORMATION |
| 14 | Pinkish-tan, punky shale. Just above top of talus slope on small hydraulic face adjacent to pond in SE¼ sec. 19, T. 21 N., R. 4 E., M.D.B.M. |

# APPENDIX C

## MEASURED STRATIGRAPHIC SECTION OF "AURIFEROUS GRAVELS" AND RELATED UNITS AT CHEROKEE MINE

(Section measured on west face of mine at point approximately 2500 feet southwest from Sugarloaf by O. E. Bowen and Mort D. Turner, California State Division of Mines, and the writer)

| | | Thickness in feet |
|---|---|---|
| | *Base of section:* | |
| (1) | *Bedrock:* Oregon City Formation ("greenstone"); slightly metamorphosed tuff, tuff-breccia, volcanic sandstone and conglomerate of Mesozoic age; deeply weathered locally | |
| | — PROFOUND ANGULAR UNCONFORMITY AND DISCONFORMITY — | |
| (2) | *"Dry Creek" (?) Formation:* sandstone, shale, claystone, minor lignite; thin-bedded alternating succession: light-gray to white, thin-bedded, fine-grained, angular-grained, fairly well-sorted, friable, argillaceous micaceous (biotite, kaolinite) quartz sandstone with thin clay-shale partings and scattered fossil plant fragments (grasses); dark gray to dark tan, firm micaceous (abundant kaolinite) clay-shale; gray to light gray, massive, locally shaly, firm, compact, even-textured, slightly micaceous claystone. Very local distribution because of disconformable position on bedrock | 0– 6 |
| | — CONFORMITY? — | |
| | *"Auriferous gravels":* | |
| (3) | Sandstone and conglomerate, interbedded, approximate ratio of 2:1; cut-and-fill, cross-bedding common; few thin beds of siltstone; white to light gray (locally orange or pale lavender stain), thin- to thick-bedded, moderately well-sorted (size), fine- to very coarse-grained, angular-grained, extremely friable to firm, argillaceous (in part), kaolinitic (to biotitic at top) quartz sandstone; white, crudely bedded, friable, fairly well-sorted (size) pebble conglomerate (pebbles well-rounded to subrounded and consist of white quartz [50-90%], chert [10-50%], and white claystone [0-20%]; matrix is prominent to predominant and is identical to sandstone described above); grades into overlying unit | 155 |
| (4) | Sandstone, white to pale buff, thin-bedded and cross-bedded, fine- to medium-grained, angular-grained, poorly sorted (size), friable, firm, argillaceous, biotitic (with minor kaolinite), quartzose; some pebbly beds; green clay-partings near base; tends to form vertical bank | 6– 8 |
| | — DISCONFORMITY — | |
| (5) | Siltstone, light yellowish-tan with reddish-brown streaks, thin-bedded, clayey, hard and firm, micaceous (kaolinite) | 3– 5 |
| | — SHARP CONTACT — | |
| (6) | Claystone, mottled brick-red or pale yellow-tan with grayish white or bluish-gray to solid brick-red, massive, firm, plastic, slightly sandy; unit thickens to north | 42 + |
| | — DISCONFORMITY — | |
| (7) | Sandstone alternating with minor siltstone; light gray to buff, thin-bedded and cross-bedded, friable, medium-grained, angular-grained, very silty, biotitic quartz sandstone; pebbles of claystone locally abundant; minor beds of light gray, thin-bedded, biotitic siltstone and thin beds of quartz-chert-claystone-pebble conglomerate near base; tends to form vertical bluff | 14–22 |
| | — DISCONFORMITY — | |
| (8) | Siltstone, orange-yellow to reddish-brown, thin-bedded, sandy and clayey, firm; grades into overlying unit | 15–23 |
| (9) | Claystone, mottled orange-brown and light gray, massive, soft, slightly silty, grading up into yellow claystone, grading up into dark gray, plastic claystone interbedded with grayish-tan to dark gray, silty, micaceous, locally sandy, plant-bearing (carbonized) clay-shale; may be gradational with overlying unit | 35 |
| (10) | Claystone, mottled yellow and gray, grading up into light-gray, soft, shaly, clayey, micaceous siltstone, grading up into gray, soft, slightly silty and micaceous (biotite), plant-bearing clay-shale; may be gradational with overlying unit | 33 |
| (11) | Claystone, blue or mottled blue-gray and red | 6 |
| (12) | Sandstone, greenish-brown to dark olive, massive, friable, very poorly sorted, fine- to medium-grained, angular-grained, argillaceous, biotitic, quartzose (many flakes of biotite are 3 or 4 mm across) | 11 |
| (13) | Claystone, dark gray (weathering to light gray), massive, compact, soft, silty; present only locally | 0–22 |
| | Maximum total thickness of "auriferous gravels" | 352 |
| | — DISCONFORMITY — | |
| | *Unnamed Eocene (?) beds:* | |
| (14) | Sandstone, light buff with orange streaks, thin-bedded and cross-bedded, extremely friable, fine- to medium-grained, angular-grained, quartzose, with certain laminae rich in "blacksand" (hornblende, magnetite); thin partings of dark-gray, sandy, firm, micaceous (biotite), fossil leaf-bearing (see locality no. 13, appendix B) clay-shale, and lenses, up to 2 feet thick, of light gray, massive, sandy, clayey, compact and firm, biotitic siltstone; sandstone at base contains abundant pebbles of claystone identical to that of underlying unit. Present only locally | 0–15 |
| | — SLIGHT ANGULAR UNCONFORMITY — | |
| (15) | *"Older basalt":* angular basaltic rubble | 200 + |

24416—650 6-64 2,500

# COLUMNAR SECTION, OROVILLE QUADRANGLE, CALIFORNIA


| AGE | FORMATION | THICKNESS FEET | DESCRIPTION |
|---|---|---|---|
| RECENT | ALLUVIUM, ETC. | ? | Sand, gravel, clay, silt; landslides, etc.; mine and dredger tailings. |
| PLEISTOCENE | FANGLOMERATE | 0-65 | Coarse debris from "older basalt" and from Tuscan Formation. |
| PLEISTOCENE | RED BLUFF FORMATION | 0-200+ | Reddish-brown conglomerate, sandstone, siltstone. |
| UPPER PLIOCENE | TUSCAN FORMATION: UNDIFFERENTIATED | 0-660 | Basaltic and andesitic mudflow, tuff, volcanic sandstone, volcanic conglomerate, tuffaceous siltstone and claystone. |
| | TUSCAN FORMATION: NOMLAKI TUFF | 0-20 | Rhyodacite-pumice lapilli tuff. |
| UPPER PLIOCENE ? | UNNAMED RHYOLITIC PUMICE TUFF | 0-25 | Rhyodacite to rhyodacite pumice lapilli tuff; exact stratigraphic position uncertain. |
| UPPER PLIOCENE ? | NEW ERA FORMATION* | 0-100 | Reddish-brown conglomerate, sandstone, siltstone |
| LOWER PLIOCENE | "OLDER BASALT"* | 80-250 | Olivine basalt flow. |
| LOWER PLIOCENE UPPER MIOCENE ? | MEHRTEN (?) FORMATION* | 0-200 | Andesitic mudflow, volcanic sandstone, conglomerate, tuff. |
| MIDDLE EOCENE | IONE FORMATION | 0-600 | Ione Formation: white to red quartz sandstone, claystone, siltstone; minor conglomerate, shale, and lignite. |
| | "AURIFEROUS GRAVELS" | 0-352 | "Auriferous gravels": quartz-chert-pebble conglomerate, quartz sandstone, claystone and siltstone; minor shale, plant fossils locally |
| MIDDLE EOCENE | DRY CREEK FORMATION | 0-75 | Gray, thin-bedded, fossiliferous shale and biotitic sandstone. |
| CRETACEOUS OR EOCENE | "GREENSTONE GRAVEL" | 0-40+ | "Greenstone"-cobble-boulder conglomerate, breccia; minor interbedded biotitic sandstone; exact stratigraphic position uncertain. |
| UPPER CRETACEOUS | CHICO FORMATION | 0-175 | Yellowish-buff, massive to thin-bedded, fossiliferous, biotitic sandstone; minor pebble conglomerate, shale. |
| MIDDLE JURASSIC ? | MONTE DE ORO FORMATION* | 1,300 | Interbedded, thin-bedded graywacke, sheared siltstone, conglomerate, volcanic sandstone, slate; plant fossils abundant. |
| MIDDLE JURASSIC | OREGON CITY FORMATION* | 3,200 | Slightly metamorphosed basic to intermediate pyroclastics, flows; interbedded volcanic sandstone, conglomerate. |
| PERMIAN (?) TO MISSISSIPPIAN (?) | CALAVERAS FORMATION | 11,000 | |
| | CALAVERAS FORMATION: PENTZ SANDSTONE MEMBER | | Sheared graywacke, conglomerate, slate, basic pyroclastic rocks, 0-3000' |
| | CALAVERAS FORMATION | | Calaveras Formation undifferentiated: slate, metavolcanic rocks, graywacke, conglomerate, chert, minor limestone. |
| | CALAVERAS FORMATION: HODAPP MEMBER | | Low-grade metamorphosed basic to intermediate volcanic rocks, 0-2700' |
| | CALAVERAS FORMATION | | |
| UPPER PALEOZOIC | UNNAMED METAVOLCANIC ROCKS | 4,400+ | Amphibole-albite-epidote (-chlorite) schist (metamorphosed basic volcanic rocks.) |

* Recent information suggests that the Oregon City Formation is Upper Jurassic; the Monte de Oro, Upper Jurassic; the Mehrten(?), lower Miocene; the "older basalt," lower Miocene; and the New Era, Pliocene(?). Dr. Creely has provided footnotes regarding these new age assignments in the text.

DIVISION OF MINES AND GEOLOGY
IAN CAMPBELL, STATE GEOLOGIST

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

BULLETIN 184
PLATE 1


## EXPLANATION

### STRATIFIED ROCKS

**QUATERNARY**

*Recent*

- Qmt — Mine and dredge tailings
- Qls — Landslides
- Qal — Alluvium

DISCONFORMITY

*Pleistocene*

- Qfg — Fanglomerate
- Qrb — Red Bluff Formation

UNCONFORMITY

Qu – Undifferentiated Quaternary sediments
Shown diagrammatically in cross section

**TERTIARY**

*Upper Pliocene*

- Tt — Tuscan Formation
- Ttn — Nomlaki Tuff Member
- Ttp — Unnamed rhyolitic pumice tuff (exact stratigraphic position uncertain)
- Tne — New Era Formation*

DISCONFORMITY

*Lower Pliocene*

- Tob — Older basalt

*Upper Miocene*

- Tm — Mehrten (?) Formation

DISCONFORMITY

*Middle Eocene*

- Ti — Ione Formation
- Tag — Auriferous gravels (includes unnamed Eocene (?) beds at Cherokee mine)

DISCONFORMITY

- Tdc — Dry Creek Formation

DISCONFORMITY

Te – Undifferentiated Eocene
Shown diagrammatically in cross section

**CRETACEOUS**

*Upper Cretaceous*

- Kc — Chico Formation
- gg — Greenstone gravel (exact stratigraphic position uncertain)

UNCONFORMITY

**JURASSIC**

*Middle Jurassic*

- Jmo — Monte de Oro Formation
- Joc — Oregon City Formation*

UNCONFORMITY

**LATE PALEOZOIC (?) MISSISSIPPIAN (?) TO PERMIAN (?)**

Calaveras Formation

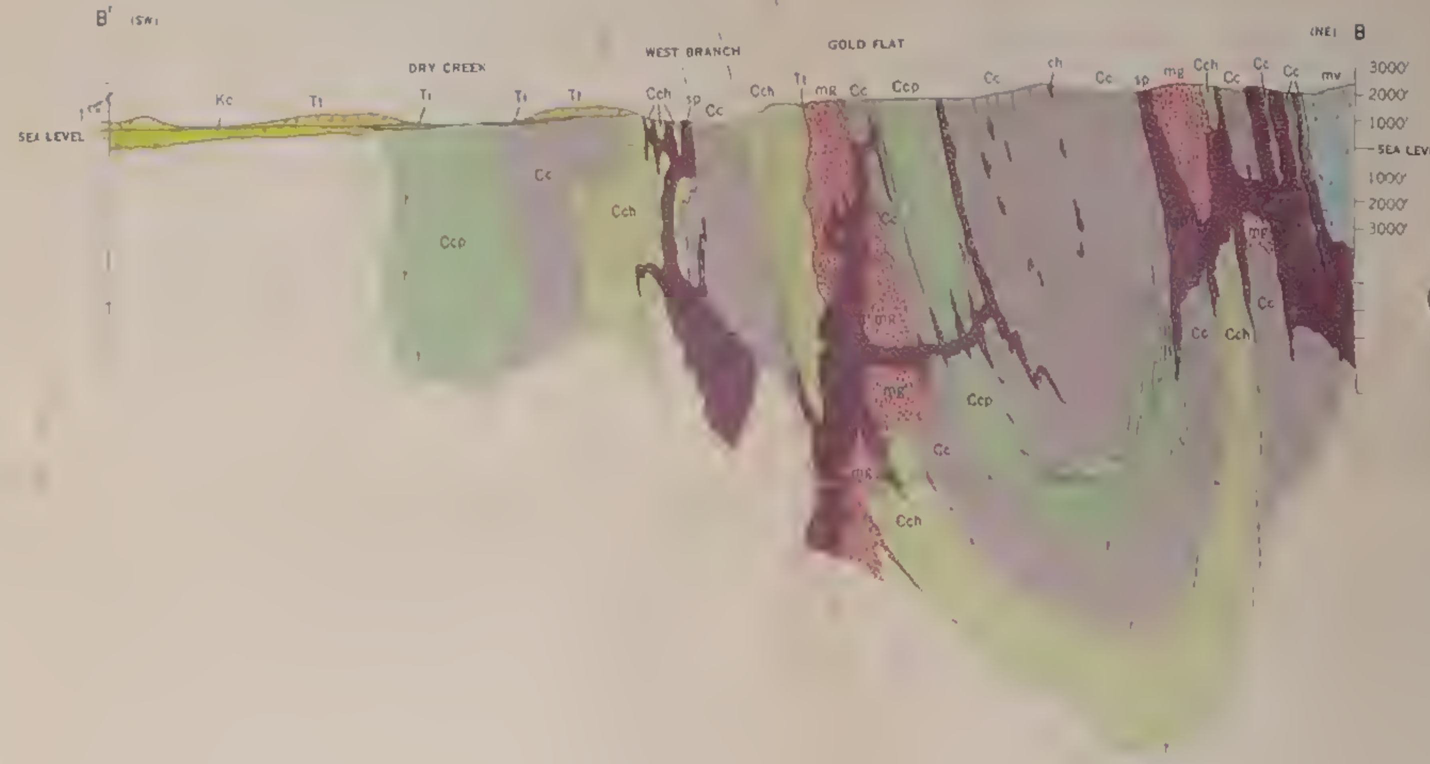
- Cc — Calaveras Formation (undifferentiated)
- Ccp — Pentz Sandstone Member* (interbedded volcanic rocks (v))
- Cch — Hodapp Member*
- ch – chert
- dc – dacite
- ls – limestone
- cg – conglomerate
- v – volcanic rocks

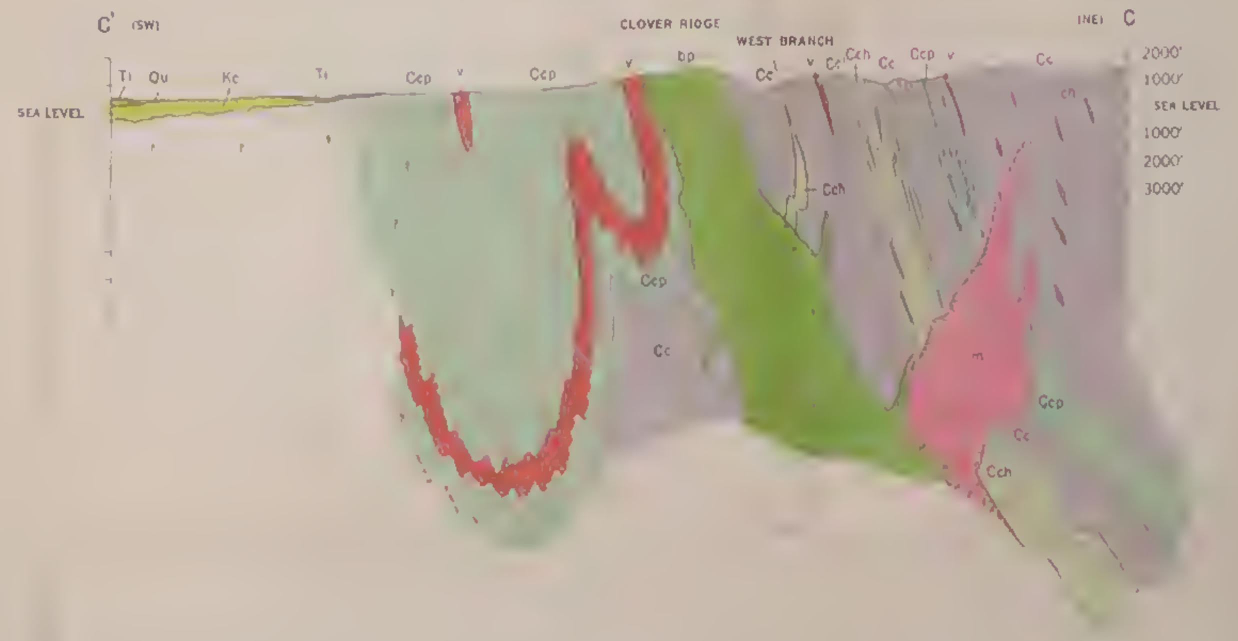
FAULT (IN PART)

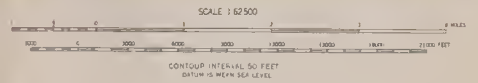
- mv — Unnamed metavolcanic rocks

### INTRUSIVE IGNEOUS ROCKS

- d — Dikes and plugs
- m — Monzonite




# GEOLOGIC MAP AND STRUCTURE SECTIONS
OF THE
# OROVILLE QUADRANGLE, CALIFORNIA

By R. S. Creely, 1954.

ls – limestone
cg – conglomerate
v – volcanic rocks

FAULT (IN PART)

mv – Unnamed metavolcanic rocks

LATE PALEOZOIC (?)

INTRUSIVE IGNEOUS ROCKS

- d – Dikes and plugs of various rocks
- m – Monzonite
- bp – Basalt porphyry
- Serpentine and talc schist
- qd – Hornblende quartz diorite
- mg – Metagabbro

* New stratigraphic name

SYMBOLS

CONTACT
- Dashed where approximately located gradational or inferred

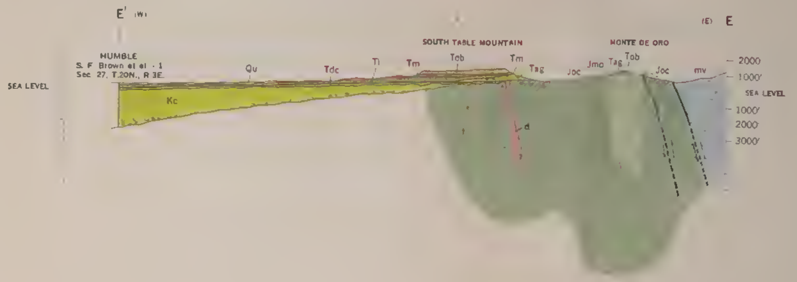
THRUST FAULTS
- Known position
- Approximate position
- Buried
- (T upper plate)

FOLDS
- Axis of anticline showing plunge
- Overturned anticline
- Axis of syncline showing plunge
- Overturned syncline

A' — A Structure sections

DIP AND STRIKE
- Bedding
- Overturned bedding
- Vertical bedding (00° on top)
- Cleavage or schistosity
- Vertical cleavage
- Bedding and cleavage parallel

- Megafossil locality
- Plant fossil locality
- Gas well (dry hole)
- Mine { au – gold quartz; p – placer gold
- Gold quartz prospect unless otherwise indicated
- s – Stone quarry
- g – Sand and gravel operation
- p – Small placer gold workings
- cr – Chromite prospect
- cl – Clay pit
- c – Coal mine (Abandoned)
- ls – Limestone quarry

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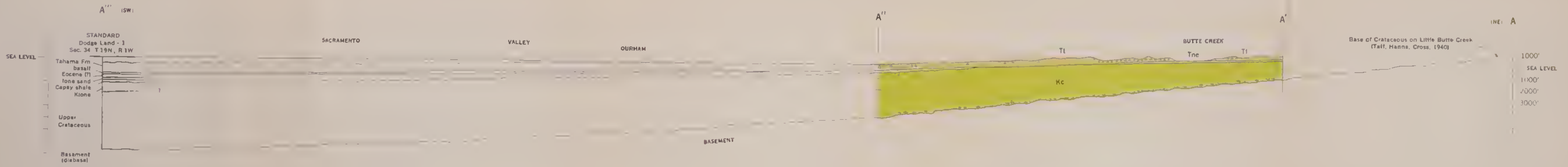


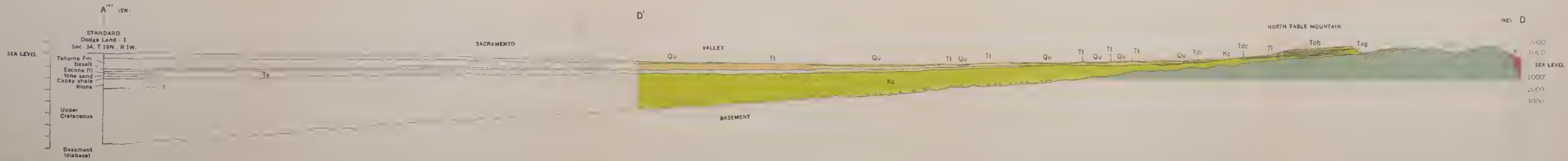



*Oroville quadrangle orientation of structure sections*